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Survivability Options for Maneuver and Transport Aircraft

Analytic Support to the Army Science Board

John Matsumura, Randall Steeb, Blake Crowe,
Nicholas Dienna, Yuna Huh, Gary Quintero,
William Sollfrey

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Preface

This monograph summarizes research conducted by RAND Arroyo Center in support of the 2002 Army Science Board Aviation Study. The purpose of this five-month study was to help the Aviation Panel of the Army Science Board explore and assess survivability concepts and technologies associated with flexible transport aircraft that could be used to make possible new operational maneuver options for the Army's future force. The results of this research are included in the final briefing and report produced by the Army Science Board; this monograph provides a more detailed account of the specific survivability research to include information on scenario, methodology, and the quantitative analytic findings. This work should be of interest to warfighters, planners, technologists, and policy decisionmakers.

This research was conducted as a special assistance activity within RAND Arroyo Center's Force Development and Technology Program. RAND Arroyo Center, part of the RAND Corporation, is a federally funded research and development center sponsored by the United States Army.

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Summary

Overcoming the Paradox in Operational Maneuver

Historically, when commanders have been able to leverage and exploit operational maneuver, they have enjoyed significant military advantages and outcomes on the battlefield.¹ Despite the growing importance of operational maneuver, it has been difficult to realize its full potential in terms of combined speed and combat capability in the new era of warfighting. On one hand, modern transport aircraft can offer speed in the delivery of forces, but they can generally move only light forces in large quantities. These forces have limited tactical mobility and combat capability once delivered. On the other hand, heavy armor forces that are tactically agile and offer highly effective ground combat capability can generally only be moved relatively slowly. Such forces are typically transported by the surface network system (e.g., roads, rail, and sea). Thus, the ability to provide combined characteristics of speed and combat capability has become a modern-day warfighter's paradox. If this inherent contradiction could ultimately be resolved, however, it could revolutionize ground operations on a future battlefield.

Over the past several years, the Army has been aggressively exploring and developing a new way to fight, one that involves much lighter armored vehicles equipped with the highest levels of informa-

¹ Refer to Chapter One of this document for a formal definition of operational maneuver.

tion technologies. Part of the utility in developing this new way to fight is to develop a solution to that paradox: air-based operational maneuver.² The combined capability of new, advanced transport aircraft in conjunction with future ground vehicles represents the central theme of a new, transformed military force. Interestingly enough, this capability is seen by some in the defense community as *long overdue*, as it is simply the next logical step in mechanized warfare and an extension of ground operational maneuver as it has been conducted in the past. By others, however, it is seen as a *bridge too far*, given technological and budgetary constraints. Nonetheless, few would argue about the overall warfighting advantage such a force would provide to the combatant commanders and the National Command Authority.

Assessing Survivability

With respect to technological constraints, one major area of ongoing debate is the survivability of large transports. More specifically, given the nature of the changing air defense environment, can large aircraft survive against modern air defense capabilities? Since the end of the Cold War, the air defense environment has in some ways become even more dangerous for aircraft. A proliferation of surface-to-air missiles (SAMs) is under way, in which advanced air defense systems ranging from man-portable air defense systems (MANPADS) to larger multivehicle high-altitude air defense systems are being openly marketed and sold by various countries. In parallel, SAM technology and system capabilities continue to improve as an asymmetric response to U.S. air supremacy.

This research sought to assess the survivability questions facing a large transport aircraft in a plausible future scenario at the small-scale

² Light forces would have the additional benefit of being strategically deployable (in a matter of days) with the appropriate allocation of airlift.

contingency (SSC) level.³ This study was conducted at the request of the Army Science Board (ASB), and it represents one part of a much broader study that is aimed at developing and shaping a Science and Technology (S&T) and Research and Development (R&D) roadmap to meet future Army aviation needs. Using a conceptual framework developed by the ASB, RAND, through its Joint Warfare Simulation and Analysis (JWSA) group, identified and then conducted a “quick-look” assessment of a range of survivability concepts and technologies. Quantitative, high-resolution models and simulations were used as part of the analytic process. Key research findings are summarized below.

Survivability Technologies Are Becoming Available

Although there is clearly a desire for aircraft to operate outside of enemy airspace (or above it), this may not always be possible. For instances where aircraft may be exposed to air defense systems, there are technologies both near term and farther term that could be integrated into the layered conceptual framework posited by the ASB. Specifically, the ASB envisioned a survivability framework that included three major tiers: preparation of the battlefield, team protection, and individual protection. In keeping with the structure of the ASB framework, the technologies were broken down according to the kind of protection or layer in which they contribute. The technologies were categorized as either *near term*, where the technology is either already proven or is potentially available within the next few years or so, or *farther term*, where the technology is seen as somewhat less mature but could be available for implementation within the next decade or so. A summary of these technologies is shown in Table S.1.

For near-term technologies, perhaps most notable are the infrared countermeasures systems, which typically involve the use of an array of passive infrared sensors to detect the launch of a missile (e.g.,

³ The threat was based on a modernized version of forces seen in Operation Allied Force in Kosovo in 1999.

Table S.1
Near- and Farther-Term Technologies for Improving Survivability
of Large Transport Aircraft

Layer of Survivability	Near-Term Technologies to Incorporate	Farther-Term Technologies to Develop
Preparation of the battlefield	<ul style="list-style-type: none">• Advanced RSTA systems (e.g., foliage penetration radar, small, agile UAVs, or unattended ground sensors)• Prep fires using area weapons (e.g., fuel air explosives)	<ul style="list-style-type: none">• Long endurance, autonomous loitering aircraft/missile, with target recognition• Long-haul command, control, and communications• Clearing of landing zones with energy weapons
Team protection	<ul style="list-style-type: none">• Low cost expendable decoys• Small high-speed anti-radiation missile (HARM)• Low-cost autonomous attack submunition (LOCAAS)	<ul style="list-style-type: none">• Unmanned Combat Armed Rotorcraft (UCAR)• Directed energy (solid state lasers) for hard kill of airborne SAM
Individual protection	<ul style="list-style-type: none">• Suite of Integrated Infrared Countermeasures (SIIRCM)• Directional Infrared Countermeasures (DIRCM)• Suite of Integrated Radio-Frequency Countermeasures (SIRFC)• Hybrid lightweight armor	<ul style="list-style-type: none">• Airborne version of the small low-cost interceptor device (SLID)• Directed energy; Multifunction electro-optics for defense of U.S. aircraft (MEDUSA)• Signature reduction• Intelligence obscurants

a shoulder-launched MANPADS). After detection, these sensors can be used to orient either a high-energy lamp or laser that can “blind” or damage the sensor of an incoming missile, causing it to lose its “lock” on the aircraft. Two specific systems that are available today are the Directional Infrared Countermeasures (DIRCM) system and the advanced threat infrared countermeasure (ATIRCM) system. These systems have already been shown to provide some protection against different kinds of IR-guided missiles.

An exemplary farther-term technology that shows theoretical promise is the application of unmanned aircraft, specifically the un-

manned combat aerial vehicle (UCAV) and the unmanned combat armed rotorcraft (UCAR). These systems can potentially serve as decoys, where they are intermixed into a transport package, or as “hunters” that rapidly neutralize air defense systems as they expose themselves to engage the flight of the transports. If this technology matures, it is possible that both applications will evolve.

Individual Technologies Show Limitations in a Robust SSC

In this research there was a broad expectation that the survivability challenge could be overcome by the novel application of technologies. However, no single technology assessed in the SSC scenario appeared to provide a complete solution for ensuring survivability of transport aircraft in defended airspace. In this quick-look analysis, both medium- and low-altitude ingress approaches were considered.

For medium-altitude cases, where the transports were flown in without any kind of protection, more than half the transports were lost. That is, on average, of the 30 aircraft in a transport package, 21 were assessed as shot down, with medium-altitude systems providing the majority of attrition.⁴ When flown at low altitude, the end results are similar: an average of 23 aircraft were shot down, with more participation from MANPADS and guided anti-aircraft artillery (AAA). From this baseline set of cases, a number of excursions were conducted to assess the impact of: joint suppression of enemy air defense (JSEAD) and destruction of enemy air defense (DEAD), local landing zone (LZ) preparation, unmanned aircraft serving as decoys, unmanned aircraft armed with anti-radiation missiles, and a notional active protection system (APS).⁵

Essentially, the results for the insertion mission show that individual concepts and technologies can result in a notable improvement

⁴ In this analysis, there were no high-altitude SAMs, such as the highly capable “double digit” SAMs.

⁵ In the analysis, assumptions were made on the success of the operation. For example, the JSEAD aspect of research was conducted parametrically, which assumed removal of SA-15s and partial removal (5 percent) of 2S6 and MANPADS.

in survivability, ranging from ~20 to ~70 percent. The use of low-altitude ingress with an unmanned platform serving as escorts and hunters, armed with a high-speed anti-radiation missile (HARM), was the most effective of the individual cases examined. In this case, we assumed the enemy would engage the formation as aircraft presented themselves, typically shooting at unmanned escorts before the transports. While this resulted in losses of escorts, the air defense systems were essentially suppressed. Despite the relative effectiveness of different survivability technologies, such improvements in survivability still translated to relatively large (and possibly unacceptable) losses of transport aircraft, ranging from 16 to 8 for a single insertion involving 30 aircraft.

A Layered Approach Can Further Improve Survivability

Greater effectiveness of the survivability technologies occurred when they were used together. Specifically, a layered, system-of-systems survivability approach provided a more effective means to achieve survivability for transports in this scenario. Using the ASB guidance, survivability starts with intelligence preparation of the battlefield, involves integration of manned and unmanned (MUM) operations through team protection techniques, and ends with platform-centric self-protection technologies.

With a combination of unmanned escorts, JSEAD/DEAD focused at elimination of the SA-15 threat, and landing zone preparation, significant improvement to survivability occurs. For the low-altitude cases, survivability improves to roughly 85 percent for low-altitude ingress (3 aircraft down). Results are not quite as favorable for the medium-altitude ingress cases, with improvement to survivability at 79 percent (5 aircraft down).

From here, the application of advanced technologies, including armed unmanned escorts along with a notional active protection system, brought about even greater improvement to the survivability of the manned aircraft platforms (at the expense of the unmanned escorts). For the low-altitude ingress case, the survivability improved to 97 percent, resulting in approximately one aircraft lost on average. Results were not as favorable for the medium-altitude case, where on

average approximately two aircraft were lost. Interestingly enough, the active protection system technology, which by itself offered little improvement to survivability of the platforms, brought about improvement when used in conjunction with other capabilities. In some ways, this last layer of defense provided a means to overcome the remaining air defense units or “leakers” that were not otherwise manageable within such a dense air defense environment.

Observations

In some ways, this research involved a highly analytic and “clean” representation of the performance of the interactions of air defense and aircraft. For example, in this research it was assumed that all enemy systems are not only operational and online, but also alert and ready to fire. With clever deception methods, it is possible that this state of readiness could be degraded. The impact of poor weather, obscurants, or other countermeasures would also reduce the effectiveness of the air defense systems. Thus, by one argument, the cases examined in this quick-look analysis tended to represent a worst case in “risk.”

On the other hand, a critical assumption here is that the JSEAD/DEAD mission, which is assumed to attrit the most capable air defense system postulated in this SSC (the SA-15), is effective. If this assumption proves to be unachievable, much of the corresponding cumulative survivability gain is lost. Additionally, a clever foe could potentially find ways to neutralize many of the technologies examined here.

Overall, this research suggests that operating in defended airspace even within the context of a SSC, albeit a sophisticated one, is a daunting proposition. Even the “best case” assessed included the loss of an aircraft. While a layered concept and associated technologies can provide dramatic improvement over flying transports alone, the application of such an aggressive deployment approach must be done judiciously. Here, operational benefits must be heavily weighed against potential risk. An analysis of transports being delivered to the

“seam” or “edge” of the defended airspace as opposed to overflight resulted in all 30 transports surviving. With this kind of deployment, the survivability concepts and technologies serve more as a useful hedge against a wide range of battlefield uncertainties, including being able to effectively find the “seam” of the defended airspace.

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List of Acronyms

AAA	Anti-Aircraft Artillery
AAPC	Advanced Armored Personnel Carrier
AD	Air Defense
AFDD	Aeroflightdynamics Directorate
AMC	Army Materiel Command
AMT	Air Maneuver and Transport
APC	Armored Personnel Carrier
APS	Active Protection System
ASA(ALT)	Assistant Secretary of the Army for Acquisition, Logistics, and Technology
ASB	Army Science Board
ATGM	Anti-Tank Guided Missile
ATIRCM	Advanced Threat Infrared Countermeasure
ATT	Advanced Theater Transport
C2	Command and Control
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CAGIS	Cartographic Analysis and Geographic Information System

CIA	Central Intelligence Agency
CMWS	Common Missile Warning System
CSAR	Combat Search and Rescue
DARPA	Defense Advanced Research Projects Agency
DEAD	Destruction of Enemy Air Defense
DFAD	Digital Feature Attribute Data
DIRCM	Directional Infrared Countermeasures
DTED	Digital Terrain Elevation Data
EO/IR	Electro-optical/Infrared
ESAMS	Enhanced Surface-to-Air Missile Simulation
FCS	Future Combat Systems
FOPEN	Foliage penetration
HARM	High-Speed Anti-Radiation Missile
IR	Infrared
ISR	Intelligence, Surveillance, and Reconnaissance
IUGS	Internettted Unattended Ground Sensors
JSEAD	Joint Suppression of Enemy Air Defense
JTR	Joint Transport Rotorcraft
JWSA	Joint Warfare Simulation and Analysis
LAV	Light Armored Vehicle
LER	Loss-Exchange Ratio
LOCAAS	Low-Cost Autonomous Attack Submunition
LOS	Line-of-Sight
LZ	Landing Zone
MADAM	Model to Assess Damage to Armor with Munitions
MANPADS	Man-Portable Air Defense System

MAV	Micro Air Vehicle
MOG	Maximum on Ground
MRL	Multiple Rocket Launcher
MUM	Manned and Unmanned
OAF	Operation Allied Force
R&D	Research and Development
RF	Radio Frequency
RJARS	RAND's Jamming Aircraft and Radar Simulation
RPG	Rocket-Propelled Grenade
RSTA	Reconnaissance, Surveillance, and Target Acquisition
RTAM	RAND's Target Acquisition Model
S&T	Science and Technology
SAM	Surface-to-Air Missile
SEAD	Suppression of Enemy Air Defense
SEMINT	Seamless Model Interface
SIIRCM	Suite of Integrated Infrared Countermeasures
SIRFC	Suite of Integrated Radio-Frequency Countermeasures
SLID	Small Low-Cost Interceptor Device
SSC	Small-Scale Contingency
TRADOC	Training and Doctrine Command
UCAR	Unmanned Combat Armed Rotorcraft
UCAV	Unmanned Combat Aerial Vehicle
USSOCOM	United States Special Operations Command

Introduction

Improving Maneuver in Conjunction with Deployability

As the Army continues along the transformation path, it is becoming increasingly dependent on new approaches for conducting ground warfare. Weapons platforms such as Crusader and various upgrades associated with current systems are being cancelled to make way for future force systems, and more reliance is being placed on capabilities that have not yet been fully proven. The fundamental tenets require the future Army to be more strategically responsive, deployable, agile, versatile, lethal, survivable, and sustainable across the entire spectrum of military operations.¹ Achieving such capabilities concomitantly will involve dramatic change.

Central to the Army transformation lies a networked, system-of-systems concept focused around a comparatively lighter-weight family of vehicles called the Future Combat Systems (FCS).² This force will exploit information to an extent never seen before. If the current vision of transformation stays the course, FCS will become the backbone of tomorrow's rapidly deploying ground fighting force, called the future force. Because this force is significantly lighter in weight than traditional mechanized forces now in the Army's inventory, it

¹ United States Army, *Concepts for the Objective Force*, White Paper, October 1999, p. iv.

² New platforms are envisioned to be approximately one-fourth the weight of the Abrams main battle tank.

will dramatically improve strategic mobility in a way consistent with current defense planning guidance.³ As a result, future ground maneuver units will be deployable into theater much more rapidly—providing many more options to the national command authority (NCA) and the respective theater combatant commanders to respond to the wide range of future crises and contingencies.

While it is clear that improved strategic mobility can provide a desirable hedge for lack of warning time and can offer improvements in combat efficiency, it is equally apparent that strategic mobility alone will not be enough to ensure success in future land combat.⁴ In a sense, getting to the theater of operations quickly and efficiently is only the beginning part of a much larger challenge for the future force. Regardless of how fast it arrives in theater, it will still have to excel in combat—in many instances against much heavier mechanized forces—in order to succeed in its mission. This will require unprecedented exploitation of information, where a combination of responsive fires and rapid operational maneuver will be key contributors for the execution of force.⁵ While plans are being drawn and roadmaps are being constructed for precision-guided fires on the future battlefield, there are relatively few efforts aimed at exploiting maneuver.

One concept that has been identified as a means to enhance the maneuver at the operational level and below for the future force is

³ A comparably sized LAV III Stryker unit or a unit equipped with Future Combat Systems (FCS) vehicles will have less than half the weight of a traditional heavy mechanized unit equipped with M1 Abrams main battle tanks (MBTs) and M2 Bradley infantry fighting vehicles (IFVs).

⁴ The Chief of Staff of the Army has indicated that the goal for deployment into theater is four days for a brigade-sized unit and five days for a division-sized unit.

⁵ Operational maneuver is defined as the act of repositioning forces in depth for immediate operations, exposing the entire enemy area of operations to direct attack, separating enemy echelons, preventing massing and resynchronization of combat power, and denying reinforcement and sustainment; operational maneuver can also be focused on seizing key terrain and decisive points in depth and destroying key enemy forces and capabilities. See *Units of Employment*, Fort Monroe, VA: U.S. Training and Doctrine Command, TRADOC Pamphlet 525-3-92.

vertical envelopment. This involves using flexible transport aircraft for the emplacement of forces as an alternative to a lengthy and potentially predictable road march (see Figure 1.1 for a notional image). Capitalizing on the lighter weight of an FCS-equipped future force, such flexible transport aircraft can be used to deploy and extract combat capability much closer to desired battle positions than strategic airlift with existing intratheater airlift (see Appendix A for a quantification of this benefit). When combined with real-time battle-field information, a flexible transport aircraft can dynamically optimize or improve the positioning of forces, thus reducing total system vulnerability while maximizing lethality. But as promising as vertical envelopment appears to be on paper, there are key issues that need to be addressed—among them affordability and survivability. Earlier RAND Arroyo Center research addressed some of the broad afforda-

Figure 1.1
One Interpretation of a Flexible Transport Aircraft: A Tilt-Rotor Aircraft Can Operate in Fixed-Wing or Rotary-Wing Modes



RAND MG123-1.1

Image courtesy of Dr. Michael Scully, Army Materiel Command, Aeroflightdynamics Directorate (AFDD).

bility and operational challenges.⁶ The research presented in this document, conducted as analytic support to the Army Science Board (ASB), extends this earlier research and focuses specifically on *survivability*.

Exploring and Assessing Survivability

The specific objective of this research effort was to explore and assess survivability ideas—both conceptual and technological—that can be used to overcome the challenges for a large flexible transport aircraft against a modern air defense environment. To begin to address the survivability challenge for this kind of an aircraft, the ASB considered how survivability was being addressed in other areas of Army transformation, including the relatively lighter-weight FCS ground vehicles themselves. Specifically, in their role against the modern inventory of heavy tanks, the relatively light (approximately one-third by weight) FCS is out-armored in combat toe-to-toe; however, survivability for these vehicles can be achieved.

One approach involves using a multitiered method to “buy back” survivability at the system level. For example, survivability for the future force unit might start with the exploitation of information technologies to set the conditions for possible FCS-versus-tank engagements. This superior information might first provide the unit commander the option for engagement or bypass. Assuming engagement is selected, this information would allow long-range indirect fire engagements (referred to as non-line-of-sight (NLOS) and beyond-line-of-sight (BLOS) engagements) to be exploited, both lethal and suppressive effects. To minimize chance encounters with enemy armor, armed robotic vehicles (ARVs) might be used as mobile “buffers,” creating a barrier and a delay between the adversary’s tanks and

⁶ See J. Grossman, D. Rubenson, W. Sollfrey, B. Steele, *Vertical Envelopment, Rotorcraft, and Operational Considerations for the Objective Force*, Santa Monica, CA: RAND Corporation, MR-1713-A, 2003.

the FCS manned vehicles. As a final method for self-defense, the FCS platforms might incorporate the use of active protection system (APS) suites located on the vehicle.



While any one of these technology areas might not be sufficient to ensure high levels of survivability, the combination of multiple technology areas—such as information assets, unmanned (and expendable) robotic systems, and advanced self-defense means, among others—can potentially provide a robust capability to fight and survive against a much heavier armored threat. Even so, such capabilities can at best enhance survivability rather than ensure it. Earlier RAND Arroyo Center research addressed the impact of such technology areas at a system level for a brigade-sized future Army force.⁷

The ASB Aviation Panel adopted a somewhat similar approach for exploring survivability for a flexible transport aircraft. Specifically, their approach consists of three basic layers (shown in Figure 1.2). Both *operational* and *materiel* actions are envisioned to provide critical capabilities toward achieving survivability.

The first layer of the plan involves extensive intelligence preparation of the battlefield. The range of capabilities here involves operations that would precede the operational maneuver mission with the transports. Operational concepts associated with this layer include high-level intelligence gathering, surveillance, and reconnaissance (ISR), reconnaissance by fire, and the extensive use of pathfinders. These concepts would collectively help to build the “big picture.” Much in the same way that intelligence would give an FCS unit commander the option to engage, this information would provide enough intelligence for selection of flight path, including the over-flight or avoidance of defended enemy airspace. Additionally, this intelligence would provide sufficient detail to enable strikes for neu-

⁷ For a detailed analysis of these technologies, see J. Matsumura, R. Steeb, T. Herbert, J. Gordon, C. Rhodes, R. Glenn, M. Barbero, F. Gellert, P. Kantar, G. Halverson, R. Cochran, and P. Steinberg, *Exploring Technologies for the Future Combat System Program*, Santa Monica, CA: RAND Corporation, MR-1332-A, 2001.

Figure 1.2
Army Science Board Aviation Panel Conceptual Framework for Achieving Survivability

 Integrated Survivability Plan Involves Three Layers for a Robust Solution 		
<u>Layers</u>	<u>Exemplary operational actions</u>	<u>Exemplary materiel actions</u>
Preparation of the battlefield	<ul style="list-style-type: none">• Use ISR (e.g., avoidance of threats)• Recon by fire• Emplace pathfinders	<ul style="list-style-type: none">• SEAD and air superiority• C4ISR connectivity• Joint/coalition contribution
Team protection	<ul style="list-style-type: none">• Tailor force packages• Dominate "local" airspace• Use UCARs as moving screen or guard for joint transport rotorcraft	<ul style="list-style-type: none">• Escort UCARs• Designated killer UCARs• HARM/loitering missiles
Individual protection	<ul style="list-style-type: none">• Fly appropriate flight profile• Use survivability tactics training• Employ assured destruction response	<ul style="list-style-type: none">• Signature reduction• Active countermeasures• Situational awareness• Vulnerability reduction

RAND MG123-1.2

tralizing key air defense positions and clearing corridors for insertion operations and landing, when overflight is chosen. Additional materiel required to accomplish this might include: more reconnaissance, surveillance, and target acquisition (RSTA) systems, to include foliage penetration (FOPEN) radar and micro air vehicles (MAVs), aggressive application of joint suppression of enemy air defense (JSEAD) and destruction of enemy air defense (DEAD) assets, leveraging a wide range of joint and coalition long-range preparatory fires, and the command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) network that would enable seamless communications between the RSTA and weapons.

The second layer of the ASB plan is team protection. The basic principle here is to enhance survivability of the transport aircraft by aggressively applying a combination of other aircraft (possibly more expendable) along with the transports. Assuming the force will be flying en masse, overwhelming firepower can be applied to suppress

or destroy possible threats. This firepower can originate from directed energy sources operating at higher altitudes, and it can also be incorporated from manned and unmanned (MUM) systems operating within a force package. This system-of-systems approach is similar to future swarming concepts that involve massing of effects and capabilities in short duration or pulses as necessary. Materiel associated with such concepts include: interoperability technologies to enable MUM, unmanned rotorcraft such as the Army/DARPA unmanned combat armed rotorcraft (UCAR) to serve as both a decoy and a lethal response against air defense attacks, and advanced weapons similar to the high-speed anti-radiation missile (HARM) or possibly long-endurance loitering weapons such as a variant of the low-cost autonomous attack submunition (LOCAAS).⁸

The third layer of the ASB plan is individual protection. The notion here is to update the self-protection capabilities of aircraft beyond the more traditional means, such as chaff and flares. There are a number of methods for improving the odds of survival for a large transport aircraft, both tactically and technologically. These might include improved nap of the earth (NOE) or contour flight profiles, advanced survivability training techniques, and enhanced onboard countermeasures to various air defense weapons. Materiel aspects associated with this kind of platform-centric protection include signature management and reduction technologies, a range of active direct-energy countermeasures, improved situational awareness, vulnerability reduction (through use of hybrid armor and redundancy in design), and a shoot-back capability.

In consideration of the growing array of the threat spectrum, each layer of the ASB framework generally corresponds to a broad capability of air defenses that might be present on the modern battlefield. For example, the “preparation of the battlefield” layer, which involves application of high-level RSTA and joint fires and JSEAD, would most likely impact the effectiveness of the long-range, high-

⁸ An early concept that offered even greater endurance was the Northrop Tacit Rainbow loitering anti-air defense system.

altitude enemy air defense systems. Because such systems are physically much larger, tend to give off much larger signatures, and are generally more difficult to reposition than small mobile systems, they can potentially be located with thorough intelligence preparation of the battlefield. With the combination of future JSEAD capabilities, such systems can potentially be neutralized before the insertion mission.⁹

In the other extreme, it may be unlikely that such high-level RSTA will be as effective against the lower-altitude SAMs, particularly the man-portable air defense systems (MANPADS). Aside from their small size and signature, these man-portable systems are relatively easy to relocate or replace and are not generally found until after they have been fired. Here, the “individual protection” layer described above provides a logical response to this kind of threat. Though chaff and flares may be a common provision today, much more advanced and capable systems involving directed energy are being developed and could be developed and incorporated into a future platform.

In the larger interpretation, modern air defense environments have become an asymmetric response to U.S. supremacy in the air. Very few countries can realistically challenge U.S. Air Force aircraft with aircraft of their own. Hence, it is possible that air defense environments will continue to grow in sophistication, making survivability of aircraft an evolving challenge. A typical integrated air defense environment may contain multiple layers of SAMs with overlapping levels of coverage, mobility, and susceptibility, among other capabilities making air operations more dangerous. Initial analyses suggest that a robust survivability approach, such as the one laid out by the ASB, will be essential if survivability is to be achieved over protected airspace.

⁹ A fundamental issue that remains to be resolved is one of the reach of SAM and the aircraft that attacks the SAM. That is, to what extent can the emerging high-altitude SAMs outrange the aircraft and weapons performing JSEAD missions?

Scope of This Research

The ASB asked RAND Arroyo Center, through its Joint Warfare Simulation and Analysis (JWSA) group, to help explore and assess concepts and technologies that might fit in to their multitiered survivability framework. Working closely with the ASB, Arroyo analysts were able to: identify representative enabling technologies, define a specific scenario for context, and quantitatively examine effectiveness as an initial or “quick-look” assessment of the impact of those concepts and technologies. In some cases, technologies were directly assessed using the JWSA suite of models and simulation. In other cases, analysis involved an exploration of parameters, through sensitivity analysis; here, qualitative discussion is provided. Given the limited scope and time of this study, in some instances only representative or exemplary concepts and technologies could be assessed.

The research addressed in this document is only one part of the larger ASB effort. The objective of the overarching ASB Aviation Panel study was to help the Army develop and shape a Science and Technology (S&T) and Research and Development (R&D) roadmap to meet future Army aviation needs.¹⁰

Organization of This Document

The remainder of this monograph is divided into five subsequent chapters. Chapter Two provides an overview of the air defense environment from a global perspective. Chapter Three identifies some of the promising survivability technologies that can be implemented in the near and farther term. Chapter Four lays out the research methodology, scenario, and hypothetical mission for a future ground force, within the context of a notional small-scale contingency (SSC).

¹⁰ The Terms of Reference (TOR) for this study are included in Appendix B. The RAND/JWSA research provided analytic support in “assessing manned and unmanned aviation needs, roles, and missions,” listed as issue 1 in the TOR.

Chapter Five describes the analytic, combat simulation–based research performed and the key findings associated with implementing the ASB framework to explore survivability. Chapter Six provides observations and conclusions. Appendix A provides a brief overview of the benefits of operational-level maneuver by air; Appendix B provides the terms of reference (TOR) for the larger ASB study. Appendix C provides a brief description of the modeling approach of a notional active protection system used in this research.

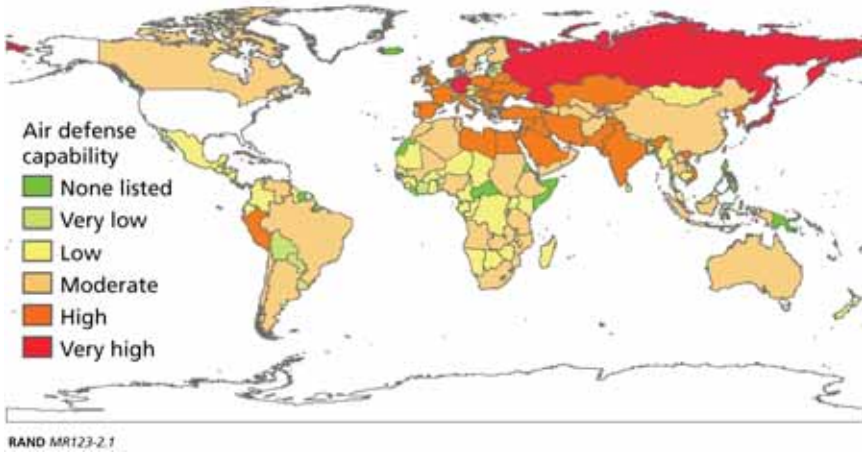
The Evolving Air Defense Environment

Air Defense Capabilities Around the World

Since the end of the Cold War, the air defense environment has in some ways become even more dangerous for modern aircraft. For one, a proliferation of surface-to-air missiles (SAMs) is under way, and the basic air defense capability—ranging from MANPADS to larger multivehicle high-altitude integrated air defense systems—is being openly marketed and sold in the arms market. For another, SAM technology and capability continue to improve. Whereas the major threat of yesterday might have been the SA-10s and SA-12s, there are now SA-20s that may confront U.S. aircraft. Additionally, the shoulder-fired MANPADS are becoming increasingly sophisticated and less susceptible to traditional countermeasures such as flares. From a broad context perspective, shoulder-fired MANPADS and other air defense (AD) capabilities are being implemented at relatively low cost as an *asymmetric* response to air power.

Figure 2.1 shows a global snapshot of the world's air defense capability as it might be interpreted today. Those countries shown in red already have sophisticated air defense capability across the spectrum. This includes low-, medium-, and high-altitude SAMs that are among the most recent generation of the technology and are in many instances even more capable than comparable U.S. systems. Countries shown in orange have capability that consists either of fewer numbers of high-end SAMs or large numbers of “previous generation” systems,

Figure 2.1
The Air Defense Threat from a Global Perspective



SOURCE: CIA *World Factbook* 2000. <http://www.cia.gov/cia/publications/factbook/index.html>.

particularly in the medium- and high-altitude domain. Their low-altitude capability is well established. Those countries shown in tan have moderate SAM capability; their profile here would be few or older radar-guided systems, MANPADS, and anti-aircraft artillery (AAA). Countries shown in light green generally have MANPADS and AAA only.

Countries that have no air defense capability by way of official record are shown in darker green. Although these countries do not have an official accounting of an air defense system capability per se, one should not conclude that such countries cannot defend their airspace. One recent example is Somalia, shown in dark green, where in 1993 two U.S. UH-60 Black Hawk helicopters were shot down by rocket-propelled grenades (RPGs). Similarly, a wide range of munitions, from small arms fire up to main tank rounds, can also pose a serious threat to rotorcraft. And because of their very small size, some

air defense systems such as MANPADS can be transported across borders without warning.¹

High-End Threats

As for the status of the higher-end SAMs, sometimes referred to as “double digit” SAMs, there is clear evidence that proliferation is under way. A summary ownership, as conducted by an extensive review of international internet sites, is shown below for existing AD systems:

- SA-10: Russia, Belarus, Iran, Serbia/Montenegro, Syria, Ukraine, China, Bulgaria, India, Slovakia, Kazakhstan, Greece (not Cyprus), Croatia.
- SA-12: Belarus, India, Russia, Ukraine, Armenia.
- SA-19 (2S6): Russia, India, China, Ukraine, Belarus, Peru.
- SA-20: tests have been conducted in 1999–2002.² China has placed an order for four batteries in 2001.³

As dangerous as the air defense threat has become, it continues to grow and become even more dangerous as more countries opt to develop and integrate air defense capabilities (perhaps as an alternative to developing a costly air force). Nonetheless, it is possible that new concepts and technologies can provide a means to improve survivability in defended airspace. The next chapter will provide an

¹ Official records suggest that there are as many as a half-million MANPADS distributed across the globe. Personal communication with Dr. Jon Grossman, engineer and analyst in military technology at RAND.

² According to some experts, the demand for SA-20 on the world market may be lower than expected, which delayed its tests. Additional information can be found at the Russian news internet site <http://www.vremya.ru/2002/12/2/27419.html>.

³ See <http://www.janes.com>, discussion on SA-10/20 “Grumble” (S-300, S-300 PMU, Buk/Favorit/5V55/48N6).

overview of technologies that can be used to implement the ASB framework of layered survivability.

Advanced Survivability Technologies

Identifying the Technologies

To assess the three-layered survivability approach developed by the ASB, an elaboration of the *operational* and *materiel actions* described in the framework shown in Figure 1.2 was required. Essentially, we used the ASB conceptual framework as a guide for organizing a range of possible concepts and technologies that could improve the survivability of a notional transport aircraft. In this phase of the research, the technologies identified by the RAND effort in Table 3.1 are meant to be exemplary technologies that could be applied to improve the odds of survival. Technologies were selected from the list and were then explored and assessed in the modeling and simulation phase of the research (as described in Chapter Four).

In keeping with the structure of the ASB framework, we broke down the technologies according to the kind of protection or layer they contribute to: preparation of the battlefield, team protection, and individual protection. In some cases, a technology could be applicable across layers; however, each was identified with the closest relevant layer. Additionally, the technologies were categorized as either *near term*, where the technology is either already proven or potentially available within the next several years or so, or *farther term*, where the technology was seen as somewhat less mature but could be available for implementation by the next decade and beyond. For the near-term technologies, in some cases, working prototypes or initial production units already exist, and where possible, available data were

Table 3.1
Near- and Farther-Term Technologies for Improving Survivability
of Large Transport Aircraft

Layer of Survivability	Near-Term Technologies to Incorporate	Farther-Term Technologies to Develop
Preparation of the battlefield	<ul style="list-style-type: none">• Advanced RSTA systems (e.g., foliage penetration radar, small, agile UAVs, or unattended ground sensors)• Prep fires using area weapons (e.g., fuel air explosives)	<ul style="list-style-type: none">• Long endurance, autonomous loitering aircraft/missile, with target recognition• Long-haul command, control, and communications• Clearing of landing zones with energy weapons
Team protection	<ul style="list-style-type: none">• Low cost expendable decoys• Small high-speed anti-radiation missile (HARM)• Low-cost autonomous attack submunition (LOCAAS)	<ul style="list-style-type: none">• Unmanned Combat Armed Rotorcraft (UCAR)• Directed energy (solid state lasers) for hard kill of airborne SAM
Individual protection	<ul style="list-style-type: none">• Suite of Integrated Infrared Countermeasures (SIIRCM)• Directional Infrared Countermeasures (DIRCM)• Suite of Integrated Radio-Frequency Countermeasures (SIRFC)• Hybrid lightweight armor	<ul style="list-style-type: none">• Airborne version of the small low-cost interceptor device (SLID)• Directed energy; Multi-function electro-optics for defense of U.S. aircraft (MEDUSA)• Signature reduction• Intelligence obscurants

used to characterize performance in the modeling and simulation effort. As for the farther-term technologies, we generally used approximations and estimates of expected performance to characterize system performance.¹

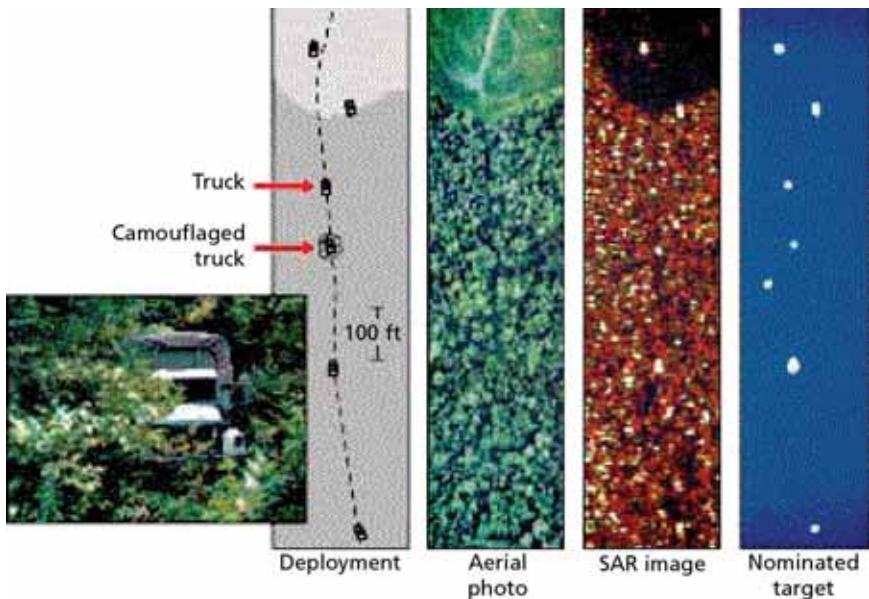
¹ Data to represent these technologies were provided by government representatives associated with the study, along with government agencies that presented technical material to the ASB Aviation Panel.

Exemplary Near-Term Technologies

Preparation of the Battlefield (Near Term)

Starting with the “preparation of the battlefield” layer, one technology area for extending the capabilities of RSTA for preemptively detecting air defense (AD) sites, particularly in complex terrain—which proved to be difficult in Operation Allied Force, 1999 (Kosovo)—is foliage penetration (FOPEN) radar. This capability can be used at standoff ranges to detect vehicles that may be hiding within foliage. While it generally cannot provide detailed information given the inherent wavelength and resolution constraints of the technology, through careful monitoring and pattern recognition, it may be possible to build information and cue other RSTA systems (see Figure 3.1).

Figure 3.1
Example of Process for Detecting Vehicles Through Foliage



RAND MG123-3.1

SOURCE: Stanford Research International (SRI). Further information is available on SRI's web site, <http://www.essd.sri.com/penetratingradar/folpen/folpen.html>.

Another technology area that could be used in conjunction with FOPEN technology to overcome the complex terrain challenge is that of unmanned platforms. The basic idea here is to bring sensors relatively close to adversary locations (i.e., suspected air defense sites). It is possible to use emerging miniaturized ground- or air-based platforms in this role. One capability appears to be that of small, agile vehicles; specifically, the Defense Advanced Research Projects Agency (DARPA) has recently demonstrated the flight of two miniature, ducted fans called micro air vehicles (MAVs) (see Figure 3.2 for MAV prototypes). These aircraft, which are approximately a cubic foot in size (~9" diameter), can carry a small sensor payload and possibly fly into and perch under treelines.² Unlike FOPEN, which generally can only detect vehicles, these systems may be able to detect or identify individual soldiers.

In addition to MAVs, the past decade has seen a number of efforts aimed at building unattended ground sensors that cross communicate. These internettted unattended ground sensors (IUGS) could be air dropped en masse into monitoring positions well before the insertion of transport aircraft. These systems, which have limited line-of-sight (LOS) in complex terrain because of their small size, could use acoustic sensors. The technology has matured to the point where a single sensor system, consisting of several microphones and a processor, can determine azimuth and class of vehicle emitting the signature (using engine harmonics). By combining multiple sensors together, it is possible to develop a non-image-based "picture" of a situation. See Figure 3.3 for an image of one variant of IUGS. Similar in size to the MAV, this system is roughly 8" by 13" in diameter and height.

One capability that remains to be resolved is robust long-haul communications and command and control of MAVs and IUGS and other comparable systems, particularly if they are to be operated with

² Personal communications with Mr. Sam Wilson, MAV DARPA program manager, December 2002.

Figure 3.2
Two Different Prototypes of DARPA's Micro Air Vehicle



RAND MG123-3.2

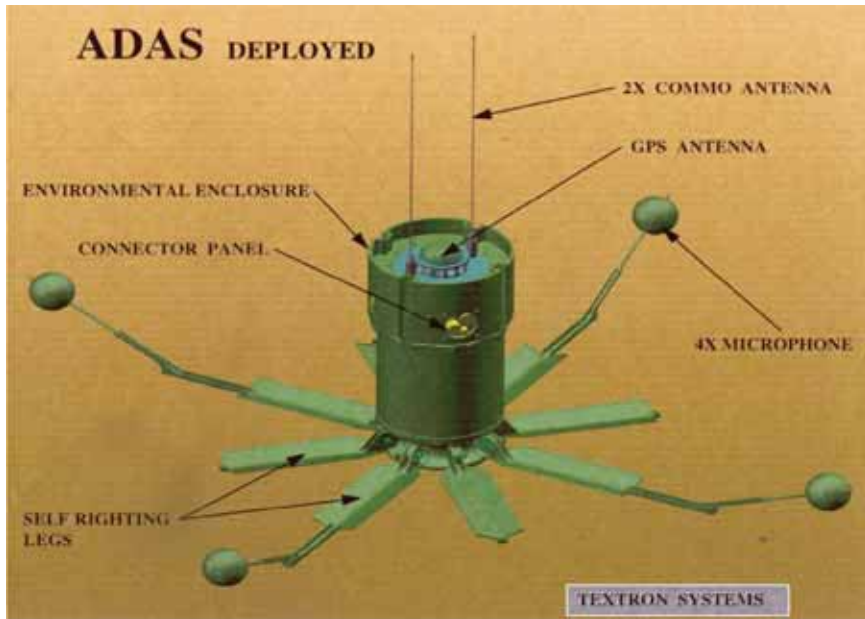


NOTE: The MAV on the left side was built by Microcraft, Inc.; the MAV on the right side, called *Kestrel*, was built by Honeywell.

large numbers and at considerable depths within enemy airspace. Perhaps the key to successful implementation of this capability will be a concomitant development of *in situ* processing, compression technology, and other developments in wireless connectivity that will allow information to be rapidly and robustly transferred from such platforms to operation centers where it can be processed and disseminated.

In some sense, the exemplary near-term RSTA capabilities appear to be highly complementary of each other. For example, FOPEN systems could be used to identify possible areas or corridors for flight operations. These areas could then be festooned with relatively low-cost and expendable MAVs and IUGS, which develop detailed information within the terrain. Based on this information,

Figure 3.3
Textron's Air Deliverable Acoustic Sensor (ADAS) Array



RAND MG123-3.3

SOURCE: Image reproduced with the permission of Textron.

processed into intelligence, focused SEAD or JSEAD could be applied as appropriate to preemptively neutralize some of the potential air defense threats.

Team Protection (Near Term)

In conjunction with improving the high-level RSTA, which would shape the overall mission, there are a number of near-term technologies within the “team protection” layer that can improve the survivability of transport aircraft. These would build on the existing capability provided by manned fixed-wing SEAD aircraft, such as the F-16CJs (that took over the mission of the F-4G Wild Weasels), that might accompany large transport aircraft as part of an insertion package. As recently demonstrated in Operation Enduring Freedom (OEF) in Afghanistan in 2002, a Predator UAV equipped with a

Hellfire missile was used in an offensive role (see Figure 3.4). Clearly, such aircraft could also be used as part of the deployment team to provide escort to large transport aircraft.

The basic idea here is to modify the class of unmanned aerial vehicles and/or decoys so that they can fly and maneuver along with the transports. Rather than preemptively finding enemy air defenses, this technology might focus on the use of such an unmanned aircraft as an expendable “point man” that might draw fire from otherwise quiescent air defense sites. An air defense system thus enticed to shoot would reveal itself for follow-on attack by either armed UAVs or manned aircraft, such as the F-16CJs.

For greater effectiveness against air defense sites, these decoys might be equipped with a small variant of the high-speed anti-radiation missile (HARM) or possibly a loitering submunition that could be designed to seek air defense sites. One example of this type

Figure 3.4
Predator UAV Carrying a Hellfire Missile



RAND MG123-3.4

SOURCE: Image taken from <http://www.airforce-technology.com/projects/predator/predator5.html>.

Figure 3.5

The Low-Cost Autonomous Attack Submunition Could Be Used to Neutralize Air Defense Sites



RAND MR123-3.5

SOURCE: Image taken from http://www.missilesandfirecontrol.com/our_products/strikeweapons/LOCAAS/product-locaas.html.

of munition is the low-cost autonomous attack submunition (LOCAAS). This submunition is relatively modest in size (~30 inches in length) and weight (~100 pounds); it is currently envisioned to use a laser radar (LADAR) seeker and can loiter for approximately half an hour.³

Individual Protection (Near Term)

There are a number of ways to improve protection within the aircraft itself. Aside from the maneuverability and flight profile used, materiel methods have traditionally included the use of armor to protect vital

³ Reference: American Federation of Scientists.

areas within the aircraft, multiple redundancy within the control system, and the use of chaff and flare as countermeasures. These are all likely to continue to provide a means for self-protection in the future, but there are other near-term technologies that can enhance survivability beyond the more traditional means. A good example of a near-term advanced technology at the “individual protection” layer is the Suite of Integrated Infrared Countermeasures (SIIRCM). SIIRCM is a combined initiative that includes the advanced threat infrared countermeasure (ATIRCM) and the common missile warning system (CMWS) shown in Figure 3.6. This system provides one perspective into the next generation of self-defense against IR (infrared) SAMs with emphasis on MANPADS.

Functionally, this system is intended to provide a fairly broad-based capability for protection against IR SAMs. It includes a suite of electro-optical sensors mounted in various locations on the aircraft for detecting missile launch and tracking SAM flight. Upon detection of missile launch (signature of plume), this system orients a lamp and/or

Figure 3.6
Components of the ATIRCM/CMWS System



Figure 3.7
Image of the DIRCM System



RAND MG123-3.7

a low-powered laser directly at the approaching SAM. This system is designed to jam the SAM optics, causing the missile to lose track of the intended aircraft. As part of the defense response, the system also includes the advanced infrared countermeasure munition (AICMM), which addresses some of the known limitations of existing flares.

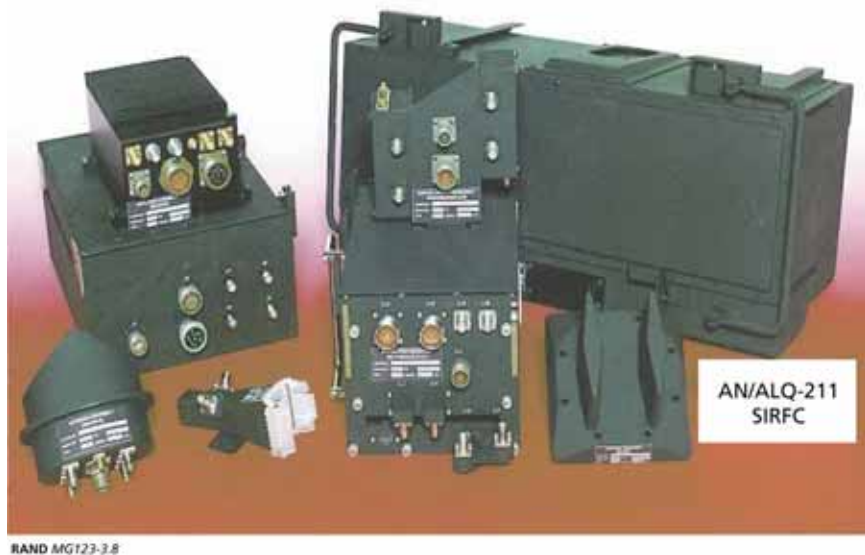
Another design based on a similar principle of defeating an IR SAM is the Directional Infrared Countermeasures (DIRCM) system shown in Figure 3.7. This system is the result of a cooperative acquisition program with the United Kingdom, initiated by the U.S. Special Operations Command (USSOCOM). This system is already being pursued aggressively to fill the need to protect large USSOCOM aircraft, in particular the AC-130 gunships and the MC-130 Combat Talons. The latter of these two aircraft is currently being used for operational maneuver in small numbers.⁴

⁴ For more information, refer to American Federation of Scientists, AN/AAQ-24 Directional Infrared Countermeasures (DIRCM), see Internet site: <http://www.fas.org/man/dod-101/sys/ac/equip/an-aaq-24.htm>.

An individual protection initiative that addresses the radio frequency (RF) spectrum of the air defense threat is the Suite of Integrated Radio-Frequency Countermeasures (SIRFC). Similar in scope to the SIIRCM and DIRCM initiatives, this system provides both awareness and a means for active defense against RF SAMs, through jamming and expendables. Specifically, the SIRFC system consists of: the advanced threat radar warning receiver (ATRWR), the advanced threat radar jammer (ATRJ), and the advanced airborne radio frequency expendables (AARFE). This system is envisioned to be effective against RF SAMs as well as radar-guided AAA. The initial intended aircraft for this system is the Army's AH-64D Longbow Apache attack helicopter.

The near-term technologies just described have already been demonstrated and in some cases are in use (albeit in relatively small

Figure 3.8
Components of Suite of Integrated Radio Frequency Countermeasures



SOURCE: American Federation of Scientists.

numbers), some with USSOCOM platforms. Despite the potential benefit, the mass integration of such capability into large armed service programs has been relatively slow. At least part of the explanation for this is attributable to the relatively high cost of such systems, e.g., self-protection suites may well exceed \$1 million.⁵

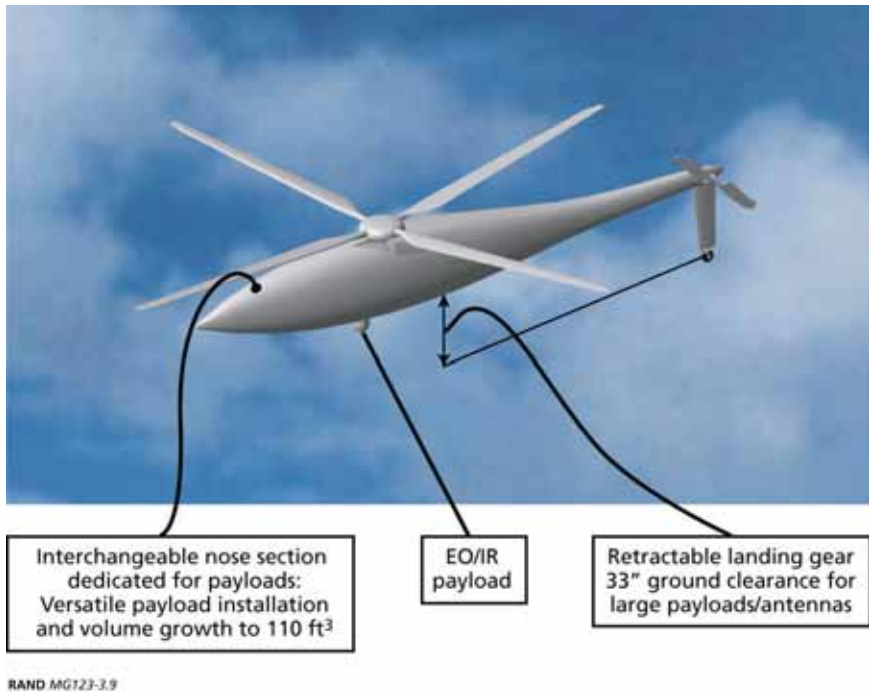
Exemplary Farther-Term Technologies

Preparation of the Battlefield (Farther Term)

Looking beyond the near-term technologies, there are a number of farther-term technologies that can further improve aircraft survivability. (As with the near-term technologies, these are intended to be exemplary rather than exhaustive.) In the “preparation of the battlefield” layer, one breakthrough technology area is in very-high-latitude, long-endurance rotorcraft, such as the Army/DARPA’s A-160 Hummingbird (shown in Figure 3.9). If this technology can be realized, it could dramatically change the way battlefield information is collected.

For example, continuous change detection could be performed from not only the same general location but also the same *perspective*, providing even greater insight into threat ground activity. Extending this technology, one can envision very-long-endurance systems that can loiter for many hours, perhaps even days, being specifically configured to autonomous and active searching for SAM sites. The use of weapons on the platform could convert such a capability into a long-endurance, lethal anti-SAM system. While such ideas are not by any means new, with loitering cruise missiles proposed, e.g., the Northrop Tacit Rainbow program, such advanced technology will enable large improvements over those envisioned only a decade ago.

⁵ Personal communications with Communications and Electronic Command (CECOM) representative involved with the development of ATIRCM.

Figure 3.9**Notional Sketch of the DARPA A-160 Hummingbird Warrior**

SOURCE: Courtesy Dr. Michael Scully, AFDD; www.darpa.mil/tto/programs/fcs_A160l.html.

Team Protection (Farther Term)

In the area of “team protection,” one exemplary farther-term system is the Army/DARPA unmanned combat armed rotorcraft (UCAR); a notional design is shown in Figure 3.10. In intent, this system is analogous to the fixed-wing unmanned combat aerial vehicles (UCAVs) but uses rotorcraft technology to provide additional flexibility for battlefield maneuver and positioning, particularly in support of ground forces.

Ideally, this system could be used in conjunction with UCAVs for suppressing and/or neutralizing enemy air defenses where both

Figure 3.10
Image of the Army/DARPA UCAR



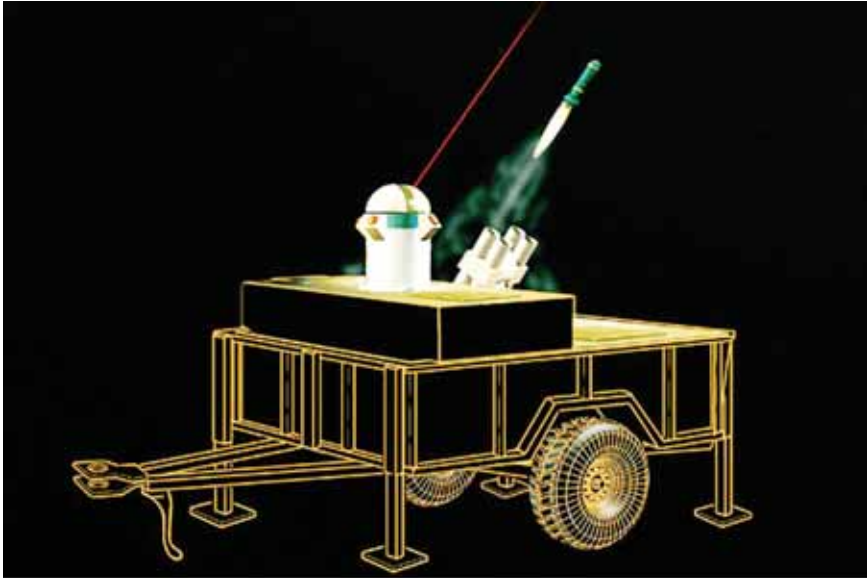
SOURCE: Image reproduced with the permission of Dr. Donald Woodbury, DARPA UCAR Program Manager.

could be used as part of a MUM force package. With hovering capability, UCARs could act as mobile airborne sentries that could be used to guard critical corridors for manned aircraft. Combined with the UCAVs, deception operations could also be conceived and integrated as part of the “team protection” layer of survivability.

Individual Protection (Farther Term)

In the area of “self protection,” members of the Army Science Board postulated an airborne version of active protection systems (APS) such as the small low-cost interceptor device (SLID). While the basic SLID concept conceived by DARPA is envisioned for ground-based vehicles providing defense against missile and artillery threats, it may be possible to adapt such a system to airborne platforms. The current SLID system consists of a relatively small, maneuverable hit-to-kill interceptor, a high-speed launcher, a passive threat warning sensor and a precision fire control system (see Figure 3.11).

Generally, for the ground-based SLID, incoming threats are engaged at ranges of up to 250 meters and can potentially include Anti-Tank Guided Missiles (ATGMs), High Explosive Anti-Tank (HEAT) rounds, mortar rounds, and artillery shells. The system is sized to reside on a relatively small platform and can be fully integrated into the other self-defense systems onboard. Because of its

Figure 3.11**Conceptual Operation of the SLID System Tracking and Engaging an Incoming Projectile**

RAND MG123-3.11

SOURCE: Image of SLID system taken from <http://www.boeing.com/defense-space/missiles/sl原因id/sl原因id.htm>.

relatively small size, a variant of this system could conceivably be mounted on a transport aircraft. Typically, SAM engagement speeds are less than many of the threats (e.g., kinetic energy projectiles) that ground vehicles are likely to face. Thus, if such technology proves to be useful for ground survivability, it appears to offer great potential for air survivability as well.

Another very high-payoff technology area for aircraft survivability is that of high-powered directed energy systems. Conceivably, solid state lasers on the order of several to tens of kilowatts (kW) can be built and integrated into a range of aircraft. Based on the U.S. Air Force airborne laser (ABL) program, this level of energy can potentially destroy as opposed to jam SAMs while airborne. Since lasers travel at the speed of light, such a capability could be provided from

higher-altitude platforms that “look down” for SAMs that have been launched as well as for the sites themselves. In addition to lasers, other forms of directed energy could be employed, such as high-powered microwaves.

Such directed energy capability could be integrated with other farther-term technologies described above. For example, directed energy along with unmanned platforms could conceivably and persistently “hunt” for SAM sites; this could be much more efficient and effective than using loitering missiles. And if weight could be reduced, such a capability could be directly integrated into the transports themselves for self-protection. Looking toward the future, this area of technology appears to offer considerable potential across a very large spectrum.

The next chapter describes the methodology and the scenario used for the analysis of the ASB survivability framework, including both the concepts and the technologies.

Methodology and Scenario for Analysis

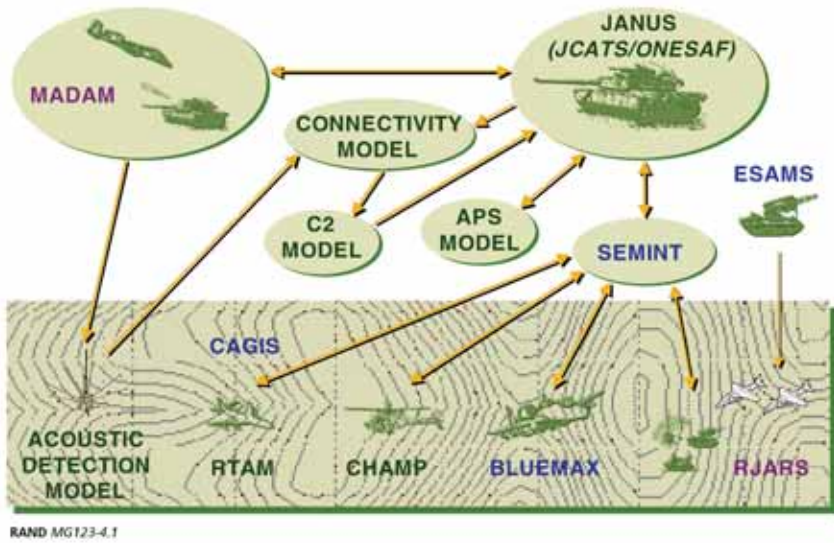
Methodology Used for the Analysis

To assess the combat effectiveness of survivability options described in the previous chapter, we used high-resolution modeling and simulation being developed with RAND's Joint Warfare Simulation and Analysis (JWSA) activity. The benefit of employing such a capability for the assessment of the ASB framework was twofold. First, it provided a hard context for discussing and debating the utility of both the operational concepts and the underlying enabling technologies. Second, it provided a direct means for quantitatively analyzing and assessing the complex force-on-force interactions, particularly between large transport aircraft and air defenses.

The key modeling and simulation suite for ground combat is centered around RAND's version of Janus (see Figure 4.1).¹ This version of Janus was augmented to allow higher-fidelity models or algorithms of new technologies, including improvements in RSTA, addition of unmanned aircraft, and self-protection means (particularly a notional active protection system) to be linked with the main Janus program. This was achieved through seamless model integration (SEMINT), which is a variation of the software developed for the

¹ Other force-on-force models within this suite of models include the Joint Conflict and Tactical Simulation (JCATS) and OneSAF (testbed version 2.0).

Figure 4.1
High-Resolution Modeling and Simulation Network at RAND



NOTE: In addition to SEMINT and the air defense models RJARS and ESAMS described in the text, other key models and simulations include: a smart/brilliant munitions model called the Model to Assess Damage to Armor with Munitions (MADAM), a Command and Control (C2) model, a model to assess Active Protection Systems (APS) based on an Army Research Laboratory (ARL) model, a Cartographic Analysis and Geographic Information System (CAGIS), the Blue Max II and CHAMP flight planners for fixed- and rotary-wing aircraft respectively, and the RAND Target Acquisition Model (RTAM).

world modeler used in the Distributed Interactive Simulation (DIS).² SEMINT not only allows different models to connect through event- (or time-) driven steps, but also allows separate processors to run the respective models/simulations, effectively increasing net processing power.

For modeling the air-to-ground interactions, we used RAND’s version of the Jamming Aircraft and Radar Simulation (RJARS),

² Developed by Dr. Jed Marti; see J. Marti, P. Kantar, W. Sollfrey, and K. Brendley, *SEMINT, Seamless Model Integration*, Santa Monica, CA: RAND Corporation, MR-403-OSD/A, 1994.

which incorporates some of the algorithms associated with the U.S. Air Force's Enhanced Surface-to-Air Missile Simulation (ESAMS). The RJARS program is based on the Jamming Aircraft and Radar Simulation (JARS) model developed at Johns Hopkins University, which has evolved at RAND to incorporate new methodologies for representing both aircraft and air defense systems.³

RJARS has the capacity to simulate the many-on-many interactions between aircraft and air defense systems. Aircraft aerodynamics are characterized by one of two flight path generators (Blue Max II or CHAMP), and such aircraft can be equipped with anti-radiation missiles. Air defense systems can be characterized as autonomous or fully integrated. Essentially, with only minor modifications to the simulation software already within the Janus suite of models and simulations shown in Figure 4.1, many of the ASB concepts and technologies were assessable within the timeframe of the study.

Since no definitive requirements or specifications data were available for the Army's air maneuver and transport (AMT) at the time of this study, broad estimates of performance were made in order to explore the ASB survivability framework. Here, the envisioned performance of the notional joint transport rotorcraft (JTR), in the form of a tilt-rotor transport, was used as a strawman concept as directed by the ASB (see Appendix A for more information).⁴ Similarly, for exploring the impact of advanced self-defense technologies such as SLID, a notional APS-like missile intercept device algorithm was created using theoretical approximations.⁵ Details of the modeling work are included in Appendix C.

³ See W. Sollfrey, *RJARS, RAND's Version of the Jamming Aircraft and Radar Simulation*, Santa Monica, CA: RAND Corporation, N-2727-1, 1991.

⁴ We coordinated system performance estimates with the AMC AFDD representative, Dr. Michael Scully, to approximate airframe performance.

⁵ We used algorithms developed by Dr. Gregory Canavan, Los Alamos National Laboratory and member of the ASB Aviation Panel, for approximating the performance of a notional missile interceptor device.

A Representative Small-Scale Contingency

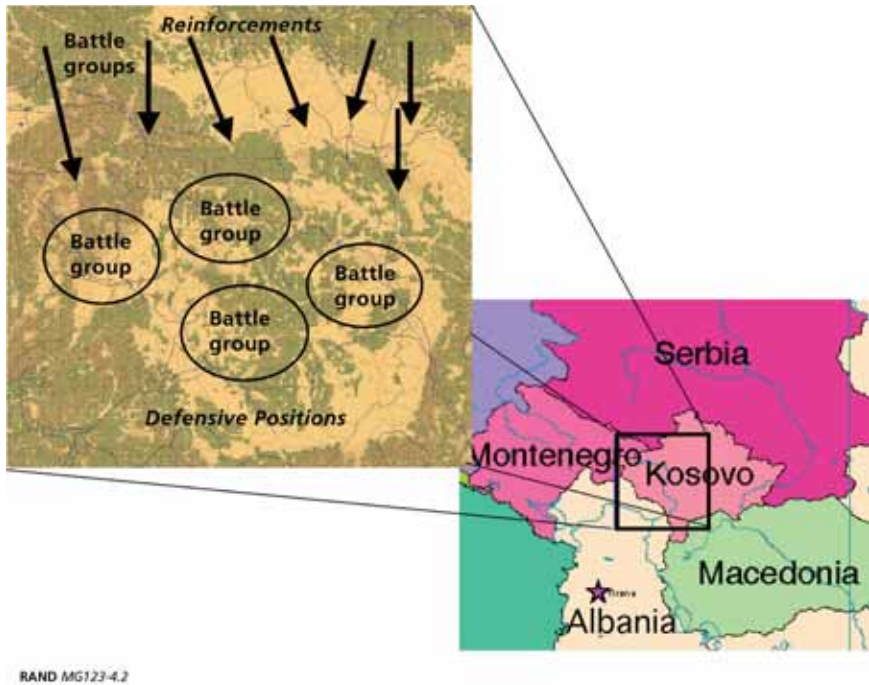
The scenario selected by the ASB for analysis of the survivability framework was the *Kosovo 2015* small-scale contingency (SSC). Originally, this scenario was developed by RAND to help the U.S. Army and the ASB explore current and future force operations in a relatively challenging SSC.⁶ In this scenario, U.S. forces are assumed to be able to strategically deploy into theater in a relatively short timeframe before an opposing force can fully occupy the terrain. Operational mobility, however, is not assumed.

The scenario involves bringing in a brigade-sized force, either a Stryker Brigade Combat Team (SBCT) or the future force Maneuver Unit of Action (UofA) to control a 100-by-100 kilometer region on the western region of Kosovo. The mission of the brigade-sized force is to put a stop to ethnic cleansing and provide security to the area. Because of the rapid reaction of the insertion, the terrain is only partially occupied by opposing forces, though more reinforcing units are on the move. On day six of this scenario, four battle groups (reinforced companies) are in the region, with seven more en route to reinforce. See Figure 4.2 for a general depiction of the region and the opposing force laydown.

This scenario was of special interest to the ASB for several reasons. First, it has a real-world foundation, since the scenario was loosely based on the Serbian materiel organization and capabilities in the region during Operation Allied Force (OAF) in 1999. Second, it constituted a challenging case for lighter maneuver forces. Specifically in OAF, dismounted infantry forces were seen as too vulnerable and too difficult to sustain, while heavy forces had limited mobility for

⁶ This research was conducted for then LTG Kevin Byrnes, U.S. Army G-8, and Dr. Michael Andrews, Deputy Assistant Secretary for Research and Technology, Office of ASA(ALT). The earlier research showed the importance of fast response and agile operational maneuver in rough terrain. The scenario was found to be demanding on all components of the U.S. ground force.

Figure 4.2
Location of Scenario and Positions of Opposing Forces



traversing the relatively fragile road network system.⁷ Third, the foliage in this environment was not technology-friendly and served as a challenging test case for exploring the ASB survivability framework.

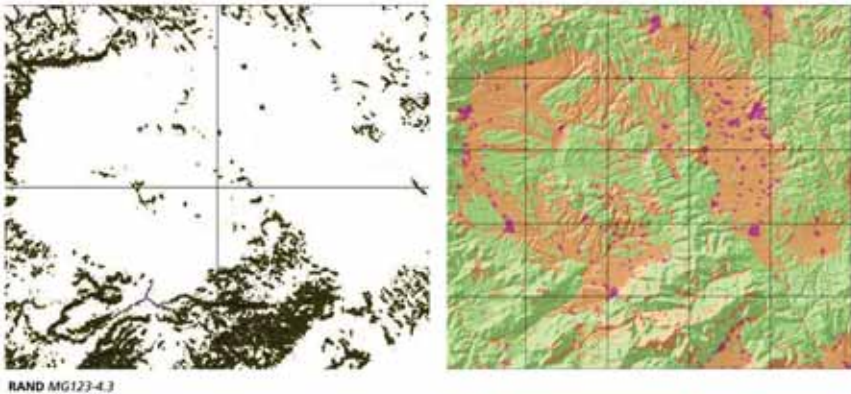
The Kosovo terrain was digitized and populated with both digital terrain elevation data (DTED) and digital feature attribute data (DFAD) in preparation for force-on-force, high-resolution modeling and simulation. Additionally, the major road network in the areas was superimposed on the terrain. A breakdown of the DTED and DFAD data from the national imagery and mapping agency (NIMA) for the 100-by-100 kilometer terrain box reveals that approximately 11 per-

⁷ It was unclear to what extent the bridges in this region could support the weight of a combat-ready M1 Abrams tank.

cent of the terrain has a slope of over 20 degrees⁸ and approximately 60 percent of the area is covered by foliage.

Although the percentage of high-slope terrain by itself does not present a major problem (for comparison, a similar analysis shows the eastern part of Afghanistan having close to 45 percent of its terrain with a slope of over 20 degrees), the location of the high-slope elevation tends to encircle the region (see Figure 4.3, left-hand image). The dark areas shown in the figure indicate where in the 100-by-100 kilometer region the slope exceeds 20 degrees. As a result, the topography creates fairly restrictive access into this particular region from the ground. Coming through Albania from the south, there are only two major mountain passes that can be used to move forces by ground. As for the location of the foliage (shown in Figure 4.3, right-hand image), it is quite evident that opposing forces would have ex-

Figure 4.3
Areas of High-Slope Terrain (Left) and Areas of Foliage in
Region of Interest (Right)



⁸ The 20-degree slope was selected merely as a point of reference, because this can be seen as limit for some ground vehicles attempting to maneuver on uneven terrain. The 11 percent frequency is an approximation calculated from cell-to-cell digital elevation data available for this region.

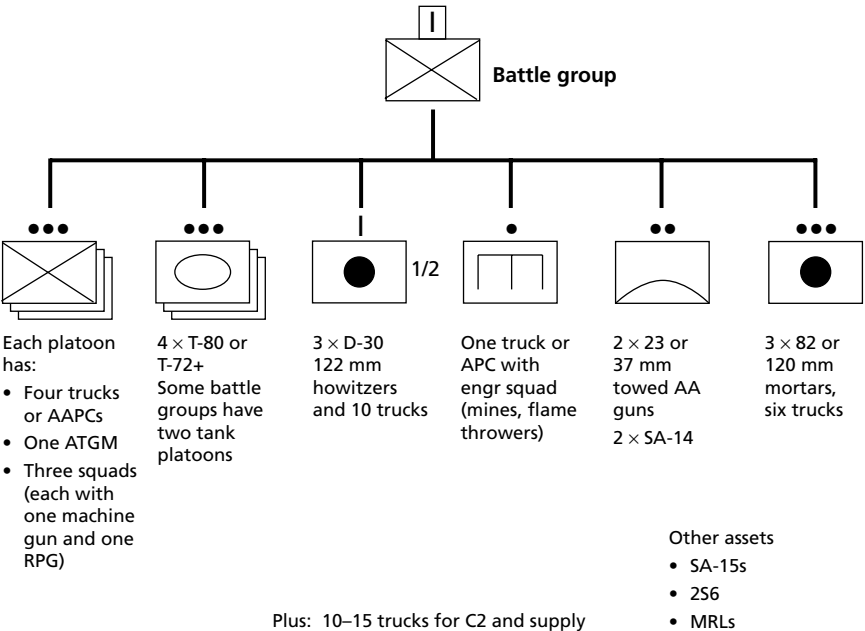
tensive options for creating a defense of this terrain, both on the hills and in the lower plain in the center of the region.

Opposing Forces in the Kosovo 2015 Scenario

For analysis purposes, the opposing force assumed in this scenario was derived loosely from the organization and materiel of the forces that were deployed by the Serbian military during OAF in 1999. In this operation, paramilitary forces were organized into reinforced companies, referred to as *battle groups*. These battle groups were seen as highly effective because they offered the combined attributes of autonomy and broad-based functionality within a relatively small unit. As a result, these groups, which consisted of a combined arms fighting force, were relatively easy to hide and easy to maneuver and had a reasonable arsenal of weapons that included long-range rocket artillery. The opposing force used in this scenario shared many organizational characteristics with the Serbian forces in OAF. However, since the timeframe was 2015, a number of materiel changes were made (see Figure 4.4 for a unit breakdown).

More modern equipment was generally substituted within the existing (perceived) battle group organization. For example, instead of the T-55 and T-72s that were within the battle groups, we assumed T-72+ and T-80s. Similarly, we modernized the artillery and the air defenses to represent improved Russian equipment, most notably, we substituted SA-14s for SA-7s, 2S6s for ZSU-23s, and SA-15s for SA-8s. Although such modernization in this timeframe is highly unlikely given the current state of the economy and available resources for that country, the notional adjustment was made solely for analytic purposes.

Figure 4.4
Organization of Opposing Force Assumed in Kosovo 2015 Scenario



RAND MG123-4.4

A Difficult Scenario for Both Air and Ground

The environment in Kosovo in 1999 proved to be a challenge for allied forces. Specifically, OAF illustrated the complexity of conducting combat from the air at medium/high altitudes in an environment rich in noncombatants and covered with foliage. Finding mobile, tactical systems was difficult; the ability to engage them was even more problematic. Rules of engagement (ROE) complicated the target servicing process. The requirement to reidentify mobile targets with electro-optical sensors once they were found by high-level RSTA often meant

that many engagement opportunities were missed.⁹ Collateral damage or the prospect for it dramatically constrained air strikes. Looking forward 15 years, even with the advent of new technologies, overcoming such challenges seems unlikely.

For the same reasons this scenario was difficult to address by air-based military assets, it would probably be a difficult one for the ground as well. For one, the combined attributes of the terrain make it difficult to gain access by ground. For example, with only two major mountain passes through Albania, ground movement into the region would entail risk. More generally, the limited maneuver space for ground vehicles seeking entry into the region and the large amount of foliage throughout exacerbate the challenge and make an offensive operation considerably more difficult. The addition of a highly flexible and adaptive opposing force operating within this terrain makes this SSC a high-risk one for future ground forces. The next chapter will illustrate the challenges associated with the operational maneuver of forces into this region, whether by ground or by air.

⁹ Personal communications with Dr. Walter Perry, Senior RAND Defense Analyst and principal investigator in research being conducted by RAND on Kosovo lessons learned.

Force-on-Force Survivability Assessment

As noted in the previous section, the *Kosovo 2015* scenario poses a difficult challenge for operational maneuver, whether by ground or by air. Force-on-force combat modeling and simulation provided an opportunity to assess survivability options for a range of operational maneuver methods. To establish a context for this discussion, we will first consider the survivability challenges associated with a somewhat more traditional approach for this environment, with operational maneuver conducted mostly on the ground. We will then present the results of the analysis of operational maneuver by air, using the ASB survivability taxonomy as a guiding framework for the analysis.

Operational Maneuver on the Ground

Earlier RAND Arroyo Center research highlighted the challenge of operationally maneuvering medium-weight vehicles on the ground through this relatively difficult, defended Kosovo terrain.¹ The first challenge associated with ground movement into the defended terrain

¹ See J. Matsumura et al., *Exploring Advanced Technologies for the Future Combat Systems (FCS) Program*, op. cit. In this earlier work, U.S. forces were assumed to be strategically deployed into theater by way of Rinas airport near Tirana, Albania. From this location, the ground forces assembled and then marched approximately 125 kilometers to the mountain passes at the Albania-Kosovo border. The mountain passes were assumed to be held by the 82d Airborne Division's division-ready brigade (DRB) and a USMC Marine Expeditionary Unit (MEU). This was the beginning point of the force-on-force modeling and simulation.

was getting access into the region. Although the surrounding terrain was assumed to be secure, the FCS ground vehicles were seen to be particularly susceptible to long-range artillery.

The main challenge was to quickly maneuver forces past the natural “choke points” in the terrain, specifically two key bridges that lead into the Kosovo flat plain region to the north. In the simulation of this maneuver, the opposing force commander/wargamer concentrated a wide range of forces and effects on these two bridges.² In this scenario, the roads leading to and past the bridges were mined and two opposing force battle groups in the south were providing overwatch of the bridges, capable of calling in long-range artillery fire and employing a wide range of direct fire weapons. Although extensive counterfire could be used to suppress the enemy artillery, this reaction usually took effect after several volleys had been received.³

The next series of ground maneuver challenges involved bypassing the many ambush points set up by the opposing forces, which were located within the treelines. From these defended positions, numerous areas were assumed to be presurveyed and predetermined as fire zones and kill sacks. The final challenge was the engagement of the main defensive locations of the opposing forces. To enhance the defense, opposing force main battle tanks used reverse slope positioning, and infantry wielding anti-tank weapons were positioned in bunkers.

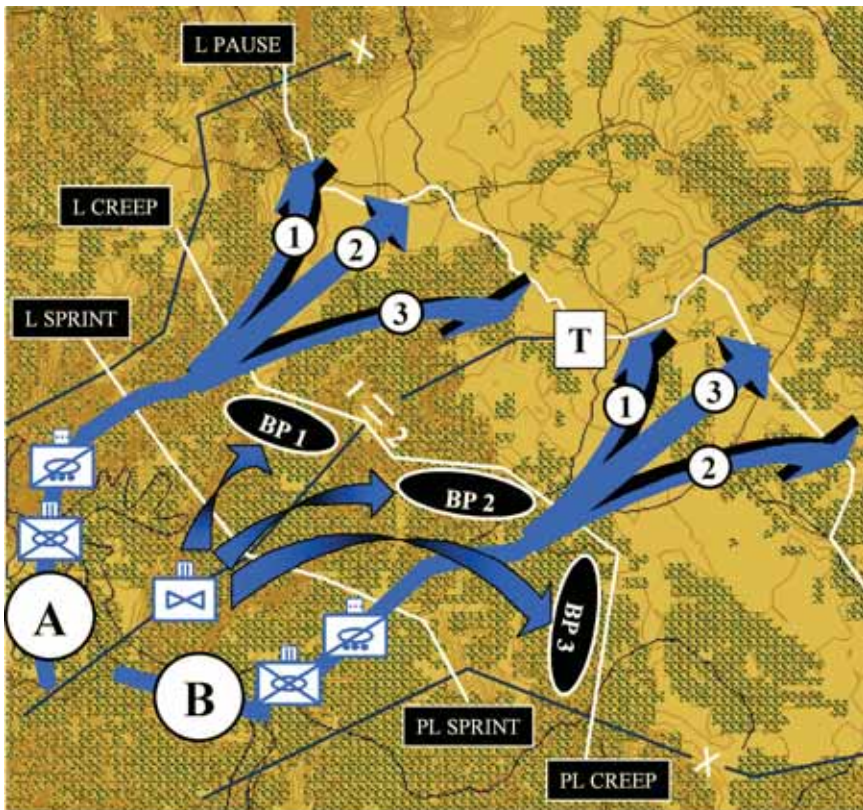
As for the organization of the U.S. ground force, the brigade-sized unit was broken into two lead columns for quick movement across the bridges. Extensive artillery-based preparatory fires were used to suppress the opposing force as friendly units crossed the bridges. Immediately after the crossing, the units slowed down and

² While destroying the bridges was also an option, this would also restrict long-term future movement across by the opposing force and slow the Kosovo population being evicted; thus, it was assumed that the bridges themselves would not be destroyed.

³ In the analysis, we found that if the opposing force is assumed to have smart munitions, akin to the U.S. Army sense-and-destroy armor (SADARM), this becomes a major problem for the ground force: very high losses occur simply getting through the passes.

began to spread out into company-sized units. Long-range fires from joint assets were used to complement suppressive artillery fire when possible. However, given the dug-in nature of the opposing force, most of the engagements involved highly lethal direct fire. Figure 5.1 shows the scheme of maneuver adopted by the representative future force ground commander. Both ground vehicle and attack helicopter movements are shown.

Figure 5.1
Depiction of the Ingress Routes Used by U.S. Ground Forces
into Defended Terrain



RAND MG123-5.1

As a result of the many challenges created by the terrain, particularly with engagements against fortified defensive positions located in the treelines, the overall outcome for the attacking U.S. ground force was generally not favorable. Although the force was able to ultimately accomplish its mission of securing the terrain, it did so with considerable losses. For example, with a medium-weight brigade-sized unit consisting of a family of vehicles, as many as one-third of the forces (a total of 109 vehicles) were destroyed as they moved into the region and across the defended terrain. Although they were able to engage and destroy a similar number of opposing forces, this was often in *reaction* to that force's attack. That is, the first shots in direct fire engagements were typically made by the opposing force.

The aggressive use of advanced technologies for survivability greatly improved the outcome of such engagements. For example, the combined effect of an active protection system (APS) and armed robotic systems for the U.S. ground force provided a concerted means for reducing losses from first-strike attacks. As a result of these particular technologies, the losses were cut in half and the lethality was doubled, resulting in a loss-exchange ratio (LER) of approximately four to one. Nonetheless, such losses were still seen as fairly high, particularly given the small-scale context of this operation.⁴

In Contrast, Operational Maneuver by the Air

If the flexible transport aircraft described earlier in this document were available for this Kosovo scenario, it might be possible to deploy forces directly into engagement positions, bypassing many of the aforementioned challenges created by the opposing force and the terrain. That is, upon landing at Rinas airport in Albania, the troops and their vehicles could be reloaded into a flexible troop transport, ideally

⁴ For a more comprehensive discussion on the results of this ground maneuver operation and associated sensitivity analysis, see J. Matsumura et al., *Exploring Advanced Technologies for the Future Combat Systems (FCS) Program*, op. cit.

with vertical landing capability. From there the ground force could be brought forward, perhaps even delivered directly into the battlefield in an advantageous position. Thus, the lengthy ground march from Rinas to the Albania-Kosovo border (approximately 125 kilometers) would be circumvented along with the high-risk ground maneuver into the heavily defended south side of Kosovo.

Instead of attacking predictably into the south as dictated by the nature of the terrain, one major advantage would be to use the flexibility of the aircraft to deploy forces into other areas.⁵ One specific option might include positioning forces directly to the western flank of the defending force, as shown in Figure 5.2. From this position, shown as landing zone (LZ) 1, the forces could reassemble into small units and move into position.

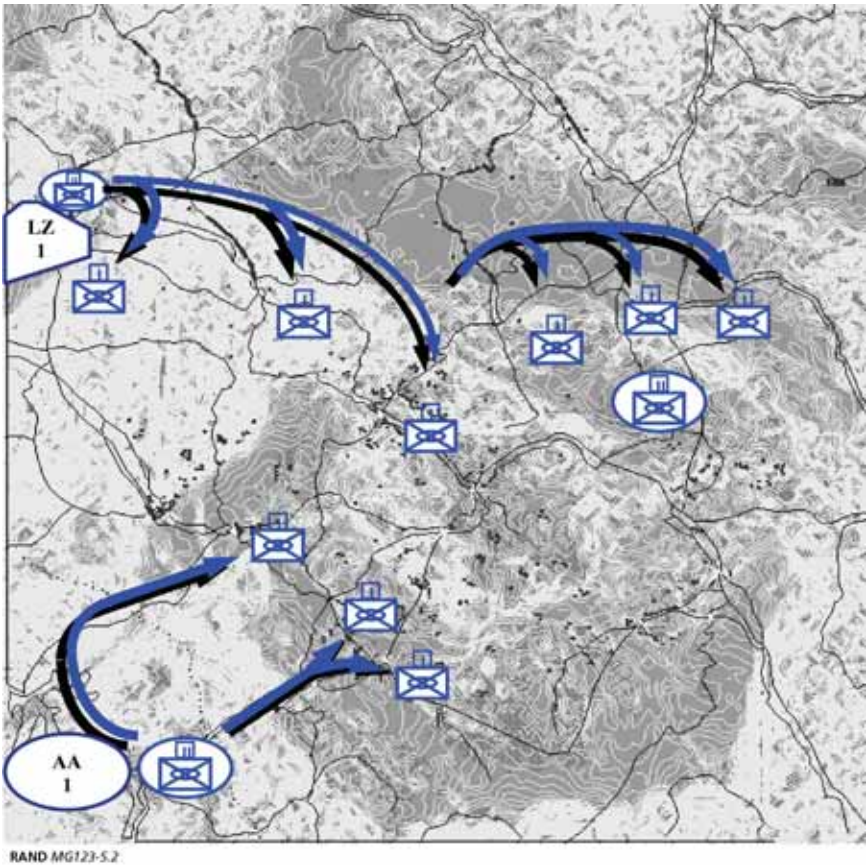
By using unit-level bounding overwatch, the ground force can maneuver from LZ 1 into opposing force territory. Since this operational maneuver effectively bypasses the defensive strongholds in the south, the U.S. ground forces more easily gain access into the region and can then attack the opposing force's reinforcements from the north. A battalion-sized force in the south can conduct a fixing action, which transitions to an attack once the opposing force is cut off from resupply.

Another specific option for air-based deployment in this scenario involves the emplacement of ground forces directly into engagement positions, by using multiple LZs (a representation of such a deployment is shown in Figure 5.3).

Clearly, this application of operational maneuver is faster and much more aggressive than the previous option, requiring overflight of defended airspace. The direct deployment of forces into forward positions can reduce the vulnerability to ground forces (e.g., mines, ambushes, kill sacks) by accentuating operational maneuver, albeit with a considerable increase in vulnerability to air defenses.

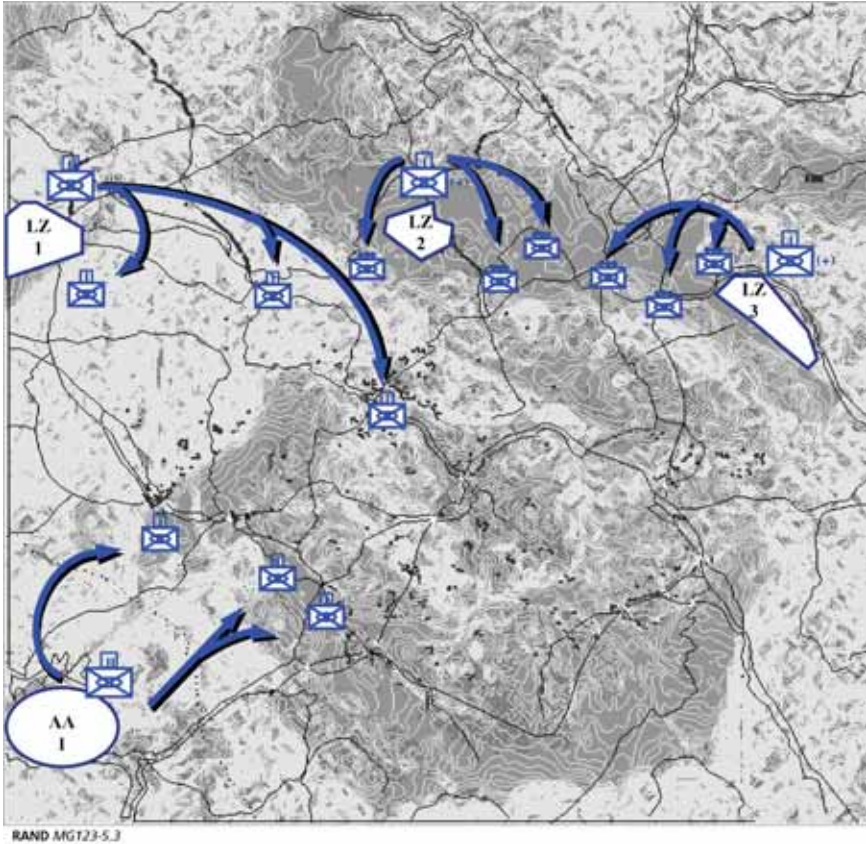
⁵ For these kinds of operations, the greater the vertical-takeoff-and-landing (VTOL) capability of the aircraft, the more flexibility it can provide for deploying forces.

Figure 5.2
One Option for Deploying Ground Forces by Air



This more aggressive deployment option involves airlifting two battalion-sized units into three different LZs. As in the previous option, the third battalion of the brigade-sized unit conducts a fixing operation to the south. As a result of the quick deployment into the northern positions, the four enemy battle groups are effectively cut off from resupply and reinforcement as soon as the ground force lands. The two battalion-sized units of FCS establish a hasty defensive position, which can easily hold the terrain from the seven en-

Figure 5.3
Another Option for Executing Operational Maneuver with Flexible Air
Delivery



croaching battle units, thus giving the advantage to the U.S. ground force. And once the four enemy battle groups have been cut off from resupply, time becomes less important because the problem has been contained. The battalion to the south can attack and engage at a pace that minimizes its vulnerability.

In this scenario, flexible and rapid operational maneuver offers key advantages. In the first option for air insertion, the deployment to a single LZ allows the U.S. force to bypass many of the defensive positions that would otherwise have to be fought through to control the

terrain. However, this deployment on the flank still requires considerable movement by ground to secure terrain. Because of the timing, the U.S. ground forces would engage on the move against the opposing forces' reinforcements.

If successful, the second option for insertion, with direct emplacement of the force directly into desired positions, further improves the ground engagement. Because of the faster deployment to the location, there is time to maneuver tactically into defensive positions (e.g., FCS vehicles can establish a defense in treelines, effectively reducing their signatures). Here, U.S. forces have the opportunity to take the first shots, and superior technology associated with force is truly leveraged with a wide range of munitions that can successfully engage the opposing forces on the move. Force-on-force simulation results quantify the improvement, suggesting a favorable LER of roughly seven to one.

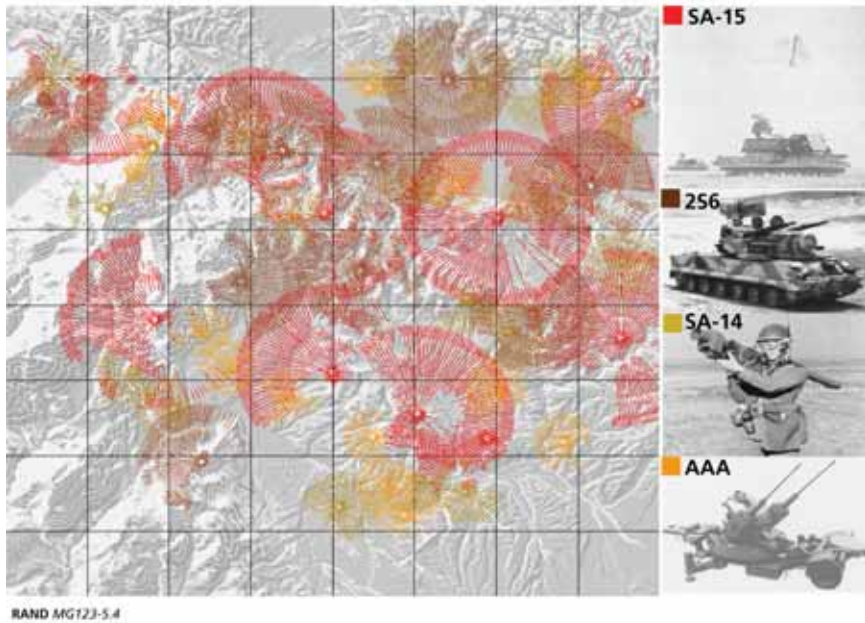
Of the two air-based deployment options, the latter was of the most interest to the ASB Aviation Panel, as it would serve as a stressing analytical case for exploring and assessing the survivability conceptual framework.

Surviving Air Insertion Is a Major Challenge

Force-on-force combat simulation and analysis shows considerable improvement in the battle outcomes when flexible operational maneuver is implemented. Generally, this capability limits the opposing force's ability to predetermine the location of the engagements (and prepare defenses) and further allows U.S. medium-weight forces to be deployed into locations that optimize mission success.

The utility and value of such operational mobility is quite evident; however, a fundamental issue that arises is whether a mission such as the one just described could be successfully executed. Specifically, the optimum locations to ensure mission success from a ground engagement perspective may be the least accessible within defended enemy airspace. Figure 5.4 illustrates the possible coverage for the air defenses assumed in this scenario. Specifically, this figure shows a depiction of the air defense systems and their respective areas of cover-

Figure 5.4
Depiction of the Coverage of Possible Air Defense Laydown
in the Kosovo 2015 Scenario



age over the roughly 100-by-100 kilometer terrain box in the *Kosovo 2015* scenario.⁶ Although LZ 1 is just inside enemy airspace, the other two landing zones shown earlier in Figure 5.3 require significant flight over enemy air defense sites.

The time constraints associated with this study allowed the exploration of only one airlift platform. The ASB Aviation Panel opted for the assessment of a tilt-rotor concept based on the Joint Transport Rotorcraft (JTR; see Appendix A for more detail). The rationale for this selection was attributed to the following: the tilt-rotor concept provided the critical element of being able to deliver forces en masse,

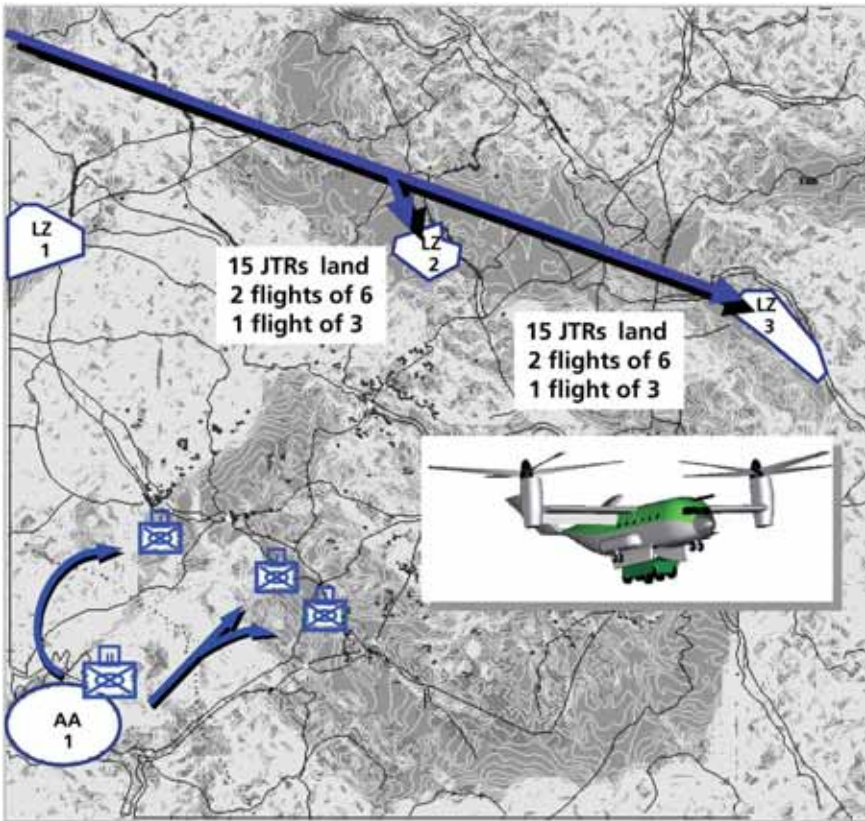
⁶ The laydown of air defenses was generally based on the numbers and organization of air defense sites seen in Kosovo during OAF; the makeup of this notional air defenses environment was coordinated with the National Ground Intelligence Center.

unbounded by airport maximum on ground (MOG), and it could deliver forces rapidly when operating in the fixed-wing mode, particularly when operating at higher altitudes.

What Might the Air Insertion Operation Look Like?

Rather than deploying the two battalions to the respective LZs in one simultaneous delivery, we postulated closely coordinated waves of deliveries (see Figure 5.5 for the ingress routes). Here, we selected a straight-line but off-attack axis path that provided some terrain-

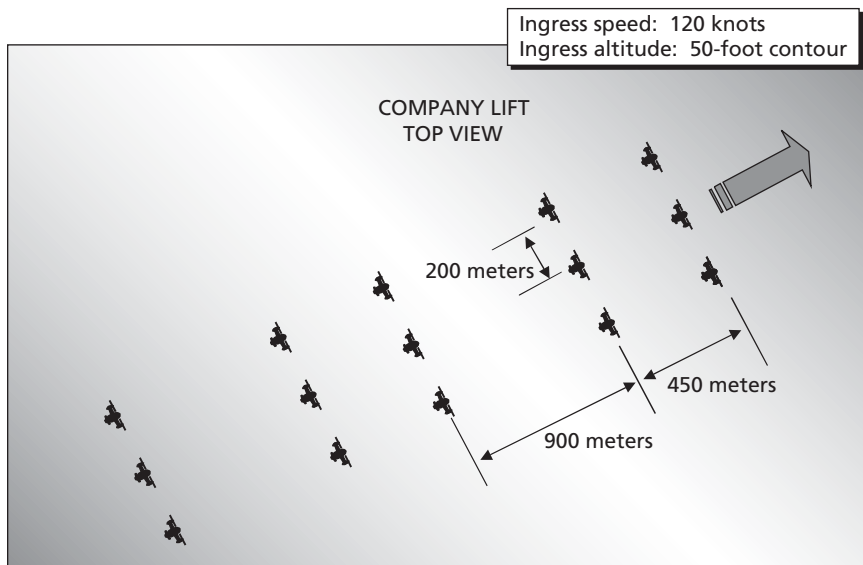
Figure 5.5
Depiction of the Air Insertion Operation (First Wave)



masking benefits. The two flights of transports travel together to LZ 2. One flight lands, the other continues on to LZ 3. Once this first wave is completely delivered, subsequent waves could follow until all vehicles associated with the ground unit are deployed. This analysis focused on the survivability of the first wave, which in a modeling perspective was the most difficult case. Also, delivery into LZ 1 was not included in this part of the analysis (e.g., no losses).

By breaking up the delivery into waves, the first units on the ground can be employed to immediately secure the area surrounding the LZs, thus reducing the vulnerability of the sequential waves. As a starting point, the plan entailed delivering roughly company-sized units (15 transports) into both LZs 2 and 3 (30 in total). In this initial wave, three transports were positioned abreast, separated by 200 meters. These transports were organized into five rows for rapid delivery into the respective LZs (see Figure 5.6 for the pattern used). From this template, different flight profile options were explored.

Figure 5.6
Spacing Associated with Delivery of a Company-Sized Unit of FCS Vehicles



Effect of Ingress Altitude

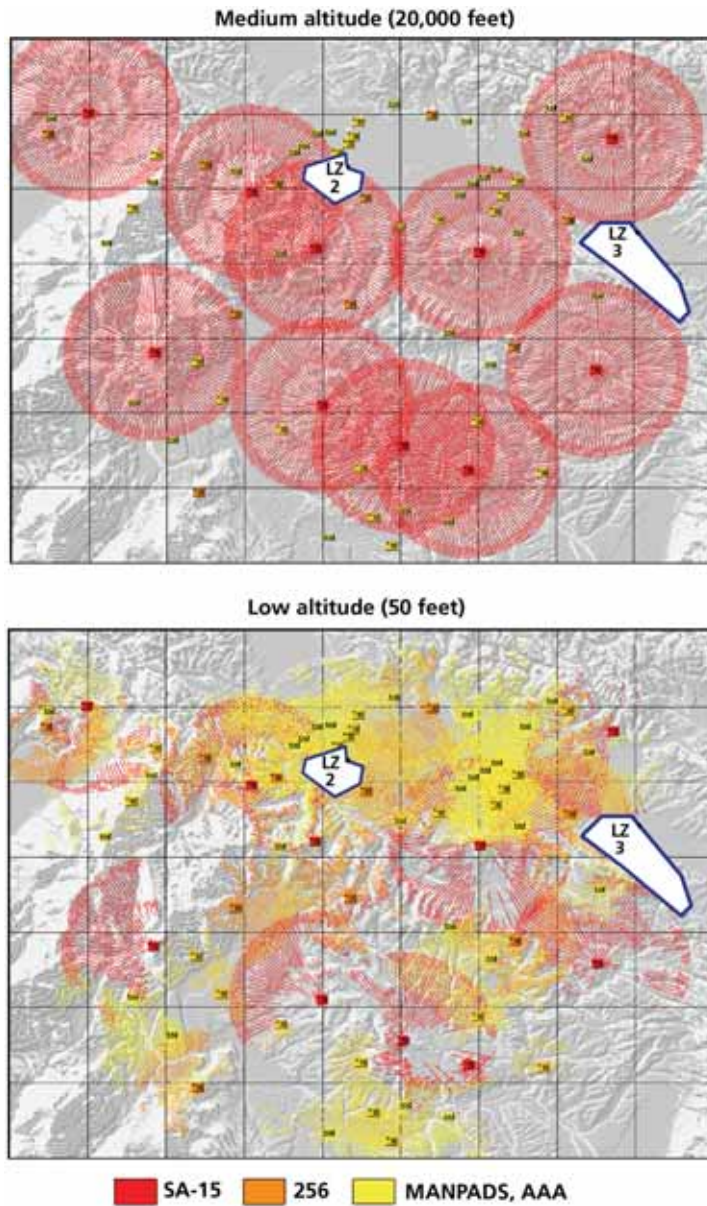
As a starting point, different flight altitudes were considered. These generally translated to different vulnerabilities to the different air defense systems. Medium-altitude flight (~20,000 feet) greatly reduces the exposure to the 2S6, the MANPADS, and the AAA, but it increases the window of exposure to the high-altitude system, the SA-15. In contrast, low-altitude flight (~50 feet) dramatically reduces the exposure to the SA-15s but brings into play the full range of low-altitude air defense systems, including the 2S6, MANPADS, and AAA. Figure 5.7 shows the difference in coverage (each type of air defense system and its line-of-sight fan is shown) at the respective altitudes.

At 50 feet, terrain can greatly reduce the LOS of the air defense systems, especially the long-range SAMs. Hence, one approach to achieving survivability would be to fly the transports low. By flying low, terrain-masking effects are achievable and generally increase with lower altitudes.⁷ Thus, by flying very low, threat radars (e.g., those of the 2S6 and the SA-15) will need to have sufficient clutter-rejection capabilities to detect the transports amidst competing ground clutter. Another approach for improving survivability might be to attempt to fly above the opposing force's air defense systems, similar to many of the fixed-wing interdiction missions flown in recent conflicts.

However, unlike interdiction aircraft (which can fly supersonic if necessary), transport aircraft generally fly considerably slower and have comparatively fewer aerodynamic evasive options if engaged. Additionally, such transport aircraft used for vertical envelopment must at some point land near or within the opposing force's airspace to deploy the ground vehicles. In cases where deployment is within the adversary's airspace, the transition flight interval can be the most dangerous for the aircraft, as the benefits of neither the low nor the high flight profiles are realized. In this analysis we examined two different flight profiles in simulation, shown in Table 5.1.

⁷ Using terrain to shield the aircraft, minimizing the LOS.

Figure 5.7
Air Defense Coverage



RAND MG123-5.7

Table 5.1
Two Different Flight Profiles Explored

Flight profile	Altitude (feet)	Speed (knots)
Low-low	50-50	120
Medium-low	20,000-50 (at landing)	300

NOTE: Low-low refers to a flight profile at 50 feet throughout the delivery mission. Medium-low refers to a flight profile that involves ingress at 20,000 feet and begins a descent approach into the LZs about 15 kilometers out.

Modeling the Effects of the Survivability Layers

Given the timeframe of the study, it was not feasible to consider all options associated with the ASB survivability framework. Instead, key capabilities (overview shown in Figure 5.8) were selected and assessed either offline or directly within the RAND Joint Warfare Simulation and Analysis suite of models and simulations.

Preparation of the Battlefield

For the intelligence preparation of the battlefield layer, we assumed knowledge of the locations of the SA-15s but not of the other air de-

Figure 5.8
Approach Taken to Address ASB Survivability Framework

Preparation of the battlefield	Capability: JSEAD/CSAR-like force package Method: Parametric overlay Outcome: Assume destruction of air defense systems
Team protection	Capability: Add decoys (UCAR-like) and vary formation, weaponry (HARMs) Method: Employment in model Outcome: Reduction in losses of air transport
Individual protection	Capability: Add missile-to-missile interceptor Method: Vary air-to-air model/data Outcome: Further reduction in losses of air transport

fense systems. Because of the density of these air defense systems (and others), the ingress approach was essentially a straight-line path, with some terrain masking along a natural ridge running east-northeast. We assumed that joint RSTA, JSEAD, and DEAD capability was able to locate and possibly destroy the high-altitude SAMs. As part of this assumption, JSEAD and DEAD would occur at both high and low altitudes. High-altitude suppression might involve current platforms (e.g., the F-16CJs) as they are currently used, and the low-altitude rotary-wing aircraft might more resemble those of a combat search and rescue (CSAR) mission. Theoretically, a broad-based capability could have considerable impact against larger air defense systems, in particular the SA-15s. Because such systems rely on search and detection radars that emit high levels of radio frequency (RF) energy, a wide range of JSEAD sensor/weapon pairings could be used to find and possibly destroy them.⁸

Even from a theoretical point of view, however, a proactive JSEAD campaign would have difficulty engaging the smaller air defense systems. Specifically in this research, the smaller and more passive systems were assumed to be harder to find and engage. Also, since JSEAD and DEAD as defined here would serve as a precursor to the actual insertion mission, any MANPADS that were found and destroyed during a successful and preemptive mission could be resurrected prior to the insertion operation. Thus, we did not assume this layer would provide an enduring effect against the more prolific of the RF systems (i.e., the 2S6) and the MANPADS and AAA. Nonetheless, from a modeling and simulation standpoint, we assessed survivability of the air transport in various states of air defense: (1) with and without a reduction of the lower-altitude systems (2S6, MANPADS, and AAA reduced by half) directly within the LZs and (2) with and without the elimination of the SA-15s.

⁸ Recent conflicts, however, suggest that even emitting SAMs that are mobile may be difficult to find and neutralize.

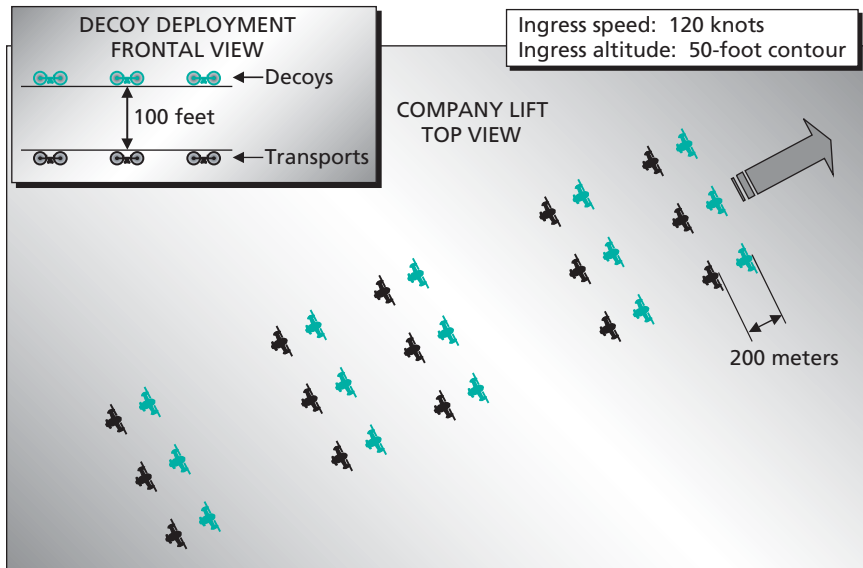
Team Protection

Turning to the team protection layer, along with exploring a range of formations, we considered two major capabilities that could enhance survivability against the harder to find and engage SAMs. The first was the addition of a decoy that could match the flight profile of the transport. For these systems, we varied the positions within the formation to include dispersed among, flanking, and in front of the transports.

For the low-altitude flight profile, one of the best options was positioning the decoys just in front and above the transports. This way, nondiscriminating opposing force air defense systems (e.g., some radar systems) are most likely to encounter and engage the decoy before the transport. This profile is shown in Figure 5.9. Positioning the decoys far forward of the transports was seen to have disadvantageous effects, as it would prematurely alert the air defense units, allowing these systems to begin the process of detecting and tracking before the manned aircraft even enter the airspace, resulting in losses of decoys and transports. For the medium-altitude paths, the decoy was flown below the transport (see Table 5.2) in two different locations.

As a means to further improve the decoys, we explored the addition of a missile that could shoot back at SAM launch sites. The system considered here was based on the missile warning capability provided by SIRFC combined with a notional high-velocity anti-radiation missile (HARM) concept. The basic idea is that upon detection of an active air defense site (possibly through launch), the decoy would fire a high-speed missile that would home in on the radar energy. This missile would be small enough to be carried by the decoy. The primary function of the missile would be to provide a hard kill of the SAM launch site or, at least, to force the site to shut down. Although in theory the SAM, which is also a high-speed missile, may have the ability to engage the decoy if it persists, there would be a reasonable probability that the site would either be destroyed or at least temporarily shut down, eliminating the launch of additional SAMs at the manned transport formation. One key assumption of this research is that the decoys are actively engaged by the threat sys-

Figure 5.9
Placement of Decoys (Green) as Part of the Transport Formation
for Low-Altitude Ingress



RAND MG123-5.9

tems. Specifically, those air defense systems with discriminating capabilities (e.g., using electro-optical adjuncts) could selectively target transports while ignoring decoys; thus, for such cases decoys must be configured to resemble the signatures of the transports or represent enough of a threat whereby elimination of the decoy becomes a priority.⁹

Individual Protection

Lastly, we assessed the contribution of a notional self-protection technology. Although DIRCM and SIIRCM via ATIRCM/CMWS appear to offer great promise, these generally apply to missiles with

⁹ Developing a low-cost decoy that resembles the signatures of a transport may be a difficult undertaking.

Table 5.2
Placement of the Decoys Relative to the Transport

Flight profile	Altitude (feet)	Speed (knots)
Low-low	Transport: 50–50	Transport: 120
	Decoy: 150–150	Decoy: 120
Medium-low	Transport: 20,000–50	Transport: 300
	Decoy: 18,000–150	Decoy: 300
	Decoy: 15,000–150	Decoy: 300

seekers (as opposed to command-link missiles). Thus, taking into account a broader spectrum for self-protection, we explored the possibility for an airborne air-to-air missile interceptor. In some sense, this is an aircraft version of active self-protection. Generally, the idea would be to use sensors onboard the aircraft to detect and track an incoming SAM. The aircraft would then launch a small guided missile to intercept the incoming SAM, based on the DARPA SLID concept described earlier. On paper, this capability appears to be achievable, although there are technological and feasibility issues that remain to be resolved.

Results from the Simulation: Impact of Individual Capabilities

One major issue to be addressed in this research was the altitude for ingress for such a large transport aircraft deploying ground forces. Earlier RAND Arroyo Center research suggested that in some instances flight at medium (or high, if possible) altitude could increase the survivability of such large transport aircraft.¹⁰ Thus, in conduct-

¹⁰ See J. Grossman, J. Matsumura, R. Steeb, J. Gordon, T. Herbert, and W. Sollfrey, *Analysis of Air-Based Mechanization and Vertical Envelopment Concepts and Technologies*, Santa Monica, CA: RAND Corporation, DB-321-A, 2001.

ing this research, both medium- and low-altitude ingress profiles were considered. Given the relatively small size of this region, the descent of the aircraft typically begins shortly after entry into enemy airspace; thus, the benefits of flying higher tended to be offset by the vulnerability experienced during transition to the ground. Essentially, the analysis suggests that it may be better to stay low and take advantage of reduced LOS and ground clutter than to fly high only to have to transition into the air defense “sweet spot” to land. Of course, terrain and different densities of air defenses may ultimately yield different results. Nonetheless, we show the results of both medium- and low-altitude ingress profiles in the reporting of the results for this particular scenario.

Medium-Altitude Cases

In the baseline case, where the first wave of transports was flown in without any kind of protection at medium altitude, more than half the transports were lost. That is, on average, 21 of the 30 aircraft were shot down, with SA-15s and 2S6s producing most of the attrition. When flown at low altitude the end results are similar, with an average of 23 aircraft shot down; there is more participation from MANPADS and AAA (averaging 6.2 and 3.0 aircraft kills, respectively).¹¹ From this baseline set of cases, a number of modeling and simulation excursions were conducted to assess the impact of (1) JSEAD/DEAD against the SA-15s, (2) JSEAD/DEAD resulting in an LZ preparation against the low-altitude systems, (3) the use of decoys flown as shown in Figure 5.9, (4) “killer” decoys armed with anti-radiation missiles, and (5) a notional APS. Results of these cases with ingress at medium altitude (20,000 feet) are summarized in Table 5.3.

Essentially, the results for the medium-altitude insertion mission show that individual concepts and technologies can result in a notable

¹¹ Average attrition is based on 30 model iterations.

Table 5.3
Survivability Outcomes in Modeling and Simulation: Transport Ingress at 20,000-foot Altitude and 300 Knots

Case Examined	Adjustment to Model/Simulation	Effect on Survivability	Cause Within Model/Simulation
Baseline	N/A	N/A	N/A
Apply JSEAD (removal of high-altitude air defenses, SA-15)	Removal of all SA-15s from engagement	~40% improvement in survivability (total of 13 aircraft down)	No kills from SA-15s, some increase in losses from other systems
Apply JSEAD (50% suppression of low-altitude air defenses)/ LZ prep	Removal of 50% of 2S6, MANPADS, and AAA in the LZs	~29% improvement in survivability (total of 15 aircraft down)	Dramatic reduction in losses from MANPADS and 2S6
Use of decoys	Addition of 1 decoy for every JTR aircraft	~22% improvement in survivability (total of 16 aircraft down)	Decoys "absorb" over half of the SA-15 and 2S6 engagements (lose ~17% of decoys)
Use armed decoys with 2 HARM each	Decoys can fire back at air defense site	~45% improvement in survivability (total of 12 aircraft down)	Losses from SA-15s and 2S6 dramatically reduced (by ~65%)
Augment transport with APS/SLID	Transport can engage incoming SAMs	No change in survivability	More shots taken to make up for missiles neutralized

improvement in survivability, ranging from 22 percent to 45 percent. The use of the killer decoy armed with HARM was the most effective of the individual cases examined. The primary reason for this was the combined absorption of the engagement and the shutting down of the SA-15 shooter. However, given the relatively high numbers of aircraft lost in the baseline case, even such improvements still translate to relatively large (and possibly unacceptable) losses of aircraft, ranging from 16 to 12 for a single insertion involving 30 aircraft. While clearly such estimates are conservative (e.g., fog of war, prospect for surprise, added complexity of air defense during night, etc.), the possibility of such large losses may be prohibitive.

Low-Altitude Cases

Conducting the operation at low altitude, and with slower speed, provided some differences in the overall outcome. These are summarized in Table 5.4. JSEAD/DEAD, particularly the effort against lower-altitude systems, was more effective here because the lower-altitude air defense systems participate more than the higher-altitude SA-15 in low-altitude ingress. Also, the addition of a decoy (one per transport) provided an even greater improvement in survivability than in the medium-altitude cases. The fundamental reason for this is attributable to two phenomena: the shorter range of the lower-altitude air defenses and the more limited LOS from the sites to the aircraft. As a result, the probability of getting a second (or third) attempt at the transport formation is much smaller than at higher altitudes, even though the aircraft are flying a much slower speed.

The addition of the HARMs to the decoy here offered less of a relative improvement over decoys alone, mostly because of lower overall numbers of second air defense attempts inherent with the low-altitude flight profile. Even with a survivability improvement of 67 percent, however, the total losses would be approximately 8 aircraft for an insertion involving 30. As with the medium-altitude cases, the notion that a single concept or technology can provide enough survivability improvement was not shown.

Table 5.4
Survivability Outcomes in Modeling and Simulation: Transport Ingress at 50-foot Altitude and 120 Knots

Case Examined	Adjustment to Model/Simulation	Effect from Baseline	Cause Within Model/Simulation
Baseline	N/A	N/A	N/A
Apply JSEAD (removal of high-altitude air defenses, SA-15)	Removal of all SA-15s from engagement	~25% improvement in survivability (total of 17 aircraft down)	No kills from SA-15s, some increase in losses from other systems
Apply JSEAD (50% suppression of low-altitude air defenses)/LZ prep	Removal of 50% of 2S6, MANPADS, and AAA in the LZs	~37% improvement in survivability (total of 14 aircraft down)	Dramatic reduction in losses from MANPADS and 2S6
Use of decoys	Addition of 1 decoy for every JTR aircraft	~52% improvement in survivability (total of 11 aircraft down)	Decoys “absorb” over half of the 2S6 engagements (lose ~21%)
Use of armed decoys with 2 HARM each	Decoy can fire back at air defense site	~67% improvement in survivability (total of 8 aircraft down)	Losses from 2S6 dramatically reduced (by ~60%)
Augment transport with APS/SLID	Transport can engage incoming SAMs	No change in survivability	More shots taken (~30% more) to achieve similar outcome

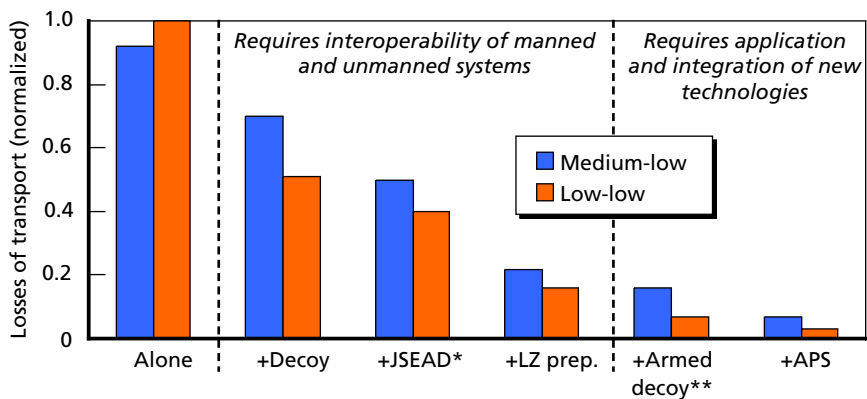
Building the Layers of Survivability: Impact of Combined Cases

The more useful application of such survivability options is seen when they are used in combination—much in line with the initial ASB hypotheses about a layered framework. An exploration of the cumulative effects of key concepts and technologies is shown in Figure 5.10.

Interoperability of Manned and Unmanned Systems

Beginning at the left side of the figure, the losses of the aircraft are normalized relative to the low-altitude ingress case with no survivability options added. When we add a combination of a decoy, JSEAD/DEAD focused at elimination of SA-15 threat, and JSEAD/DEAD aimed at reducing SAMs in the LZs, substantial improvement occurs. For the low-altitude cases, survivability improves roughly 85 percent for low-altitude ingress. Results are not quite as

Figure 5.10
Impact of Combinations of Options for Achieving Survivability
in Kosovo 2015 Scenario



*Assume successful removal of high/medium-altitude SAMs.

**HARM weapons launched by decoy/escort.

favorable for the medium-altitude ingress with these kinds of capabilities.

Analyzing the results further, the addition of the unmanned platform as decoys (one for every transport) improved the survivability of both flight profiles, but in different ways. This result is attributable to the correlation between exposure windows and numbers of SAMs fired. In the low-altitude cases, the windows tended to be shorter as the aircraft flew in and out of the LOS of the AD units. The sequence of events required before launching most SAMs and AAA combined with relatively short exposure windows reduced the number of SAMs launched per site. For the medium-altitude cases, the addition of the decoys had a lesser effect, mostly because windows of exposure tended to be longer (particularly evident during the drop-down phase of the mission). As a result, more shots per site were achieved. Flying the decoys at 15,000 as opposed to 18,000 feet resulted in minor differences in effectiveness.

The addition of an aggressive JSEAD/DEAD campaign to remove all SA-15 sites was a major factor governing the survivability of the transports. Interestingly enough, it had a similar impact on both flight profiles, which was not originally expected. Though the number of encounters went down markedly in the medium-altitude portion of the medium-low flight path, this is made up for with the later portion of the path as the aircraft must negotiate the 15-kilometer approach into the LZs, where terrain masking is not possible. Although the possibility of a more localized approach was evaluated (auguring down to the ground in a relatively small area), it turned out that the transports were then more vulnerable to local enemy air defense systems, particularly MANPADS, which had very long windows of opportunity to engage the transports.

The active clearing of the LZs, where roughly half of the lower-altitude air defense systems were removed, resulted in improved survivability for both flight profiles. Because both medium-low and low-low paths must end in the LZs, the reduction of such local defenses had a notable impact in both cases.

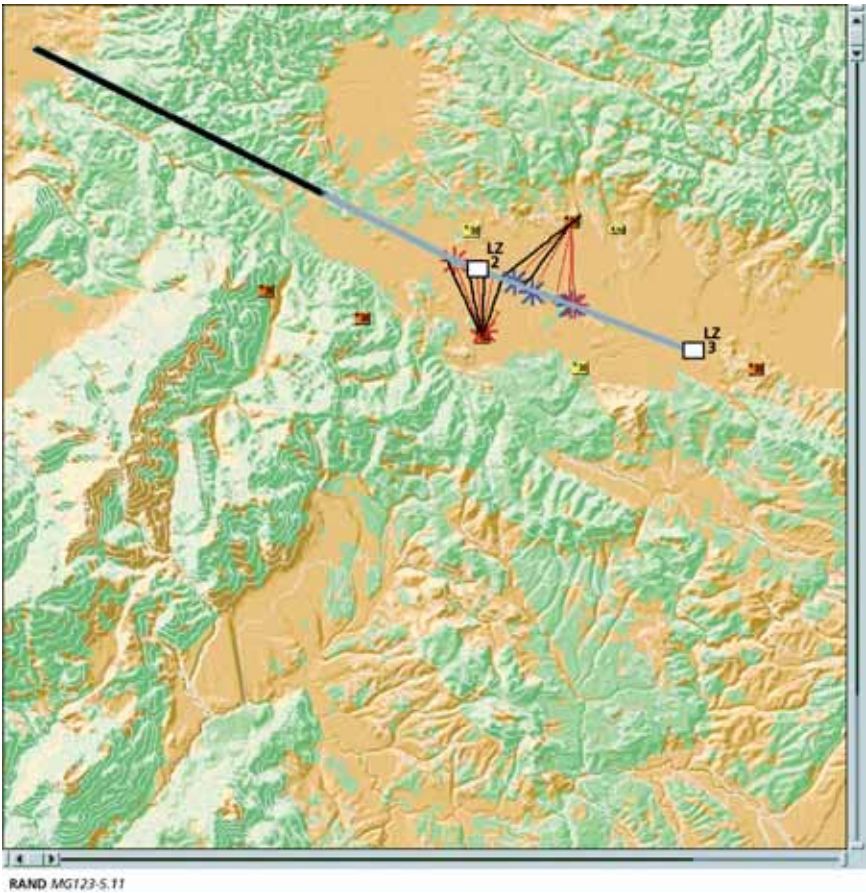
Integration of New Advanced Technologies

Additional technologies, to include arming the decoy and adding a form of active protection, yielded even greater improvement to the survivability of the manned aircraft platforms. For the low-altitude ingress, the survivability was improved 97 percent, resulting in approximately one aircraft lost on average. Results were not as favorable for the medium-altitude case, where on average approximately two aircraft were attrited.

Arming the decoys with a HARM-like anti-radiation missile further improved survivability of the manned platforms in both flight profiles; however, the impact was somewhat less for the medium-altitude profile. The reason for this reduced effect was the a priori removal of the SA-15s from the JSEAD/DEAD mission. That is, because the most predominant threat was neutralized, the weapon on the decoy had fewer opportunities to be used. The 2S6s, however, were not affected in the same way. To explore this issue further, we assessed two different altitudes to fly the decoys (18,000 feet and 15,000 feet) within and out of range of the 2S6, respectively. In the later case, the 2S6s were “enticed” to shoot, and as a result, more decoys were lost. However, when the decoys were armed, a greater reduction in 2S6s also occurred. Although flying armed decoys as intentional targets reduced the number of air defenses, it eliminated many of those 2S6s that otherwise could not engage the transports operating at medium altitude. This was not the case for low-altitude ingress, where the transports were generally vulnerable to the 2S6s throughout their flight path.

Interestingly enough, the active protection technology (APS/SLID), which by itself offered little improvement to the survivability of the platforms, provided considerable improvement when used in conjunction with other protection capabilities. In some ways, this last layer of defense, which became overwhelmed and saturated when used by itself, provided a means to overcome the remaining air defense units or “leakers” that were not neutralized after an aggressive survivability campaign.

Figure 5.11
RJARS Display of a Combined Survivability Case



For illustrative purposes, Figure 5.11 shows an RJARS graphic display of one run of the combined case discussed above. The black line shows the initial path of the 30 transports, which are heading east southeast. As they become “detected and tracked” by the opposing force’s air defense units, the line becomes gray. Although the aircraft are detected by two 2S6 units (shown as orange boxes) to the southwest, these air defense units do not have sufficient time and range to engage with success.

Instead, the 2S6 unit to the east of these sites is the first of two primary shooters. This 2S6 unit fires four SA-19 SAMs. The first of the four successfully downs one of the 15 transports heading to LZ 2 (shown by red colored asterisk). The remaining three shots from this 2S6 are taken at the 15 transports heading to LZ 3. All three miss; two arrive to engage in the end-game but fail to kill (one due to the APS/SLID) and one loses track. The 2S6 site to the north fires five SA-19 SAMs. The first two successfully attrit decoys (as shown by blue asterisks), the third misses its target, the fourth engages another decoy, and the fifth downs a transport (as shown by the red asterisk). The six black lines extending from the aircraft paths to the SAM sites represent the path of the HARM-like missiles fired from the decoys. Four missiles were fired at one SAM site, the fourth resulting in a neutralization of the site. Two missiles were fired at another SAM site, with neither resulting in a kill. The two AAA units (light orange) and the MANPADS (small yellow box) are too far out of range to successfully engage the aircraft.

Implications of Results

In some ways this research involved a highly analytic and “clean” representation of the performance of the air defense to aircraft interactions. For example, in this research it was assumed that all enemy systems are not only operational and online, but also alert and ready to fire. With clever deception methods, it is possible that this state of readiness could be degraded. The impact of poor weather, obscurants, or other countermeasures would also reduce the effectiveness of the air defense systems. Thus, by one argument, the cases examined in this quick-look analysis tended to represent a worst case in “risk.”

On the other hand, a critical assumption here is that the JSEAD/DEAD mission, which is assumed to attrit the most capable air defense system postulated in this SSC (the SA-15), is effective. If this assumption proves to be unachievable, much of the corresponding cumulative survivability gain shown in Figure 5.10 is lost. Additionally, a clever foe could potentially find ways to neutralize many of

the technologies examined here. One example may be the threat use of optical tracker adjuncts (to radar-based SAMs) that could discriminate between decoys and transport aircraft. These could also provide the option for passive engagement capability, albeit with reduced range.

Overall, this research suggests that operating in defended airspace even within the context of a SSC, albeit a sophisticated one, is a daunting proposition. Even the “best case” assessed included loss of an aircraft. While a layered concept and associated technologies can provide dramatic improvement over flying transports alone, the application of such an aggressive deployment approach must be used judiciously. Here, operational benefits must be heavily weighed against potential risk.

An analysis of transports being delivered to the “seam” or “edge” of the defended airspace as opposed to overflight resulted in all 30 transports surviving. With this kind of deployment, the survivability concepts and technologies serve more as a useful hedge against a wide range of battlefield uncertainties, including being able to effectively find the “seam” of the defended airspace.

Conclusions

Observations from *Kosovo 2015*

The assessment of the survivability concepts and technologies suggests that no single technology option will provide a complete solution for ensuring the survivability of a flexible transport aircraft in defended airspace.¹ Similar to the survivability challenge for the FCS ground vehicles, a system-of-systems approach will ultimately be necessary to achieve survivability in even modestly defended airspace. In this research, focusing on our *Kosovo 2015* scenario, survivability starts with intelligence preparation of the battlefield, involves integrating manned and unmanned (robotic) platforms, and ends with platform-centric survivability technologies.

The reason a layered, system-of-systems approach appears to be a prudent one parallels the argument for a layered defense for the FCS ground vehicles. Although improved levels of intelligence will become available over the next decade or so, this information will still be imperfect. This is to be expected: information can be obtained and processed better in some circumstances than others; relatively simple terrain features, such as foliage, can dramatically influence the ability to gather information. The venue for combat can also affect the ability to gather information (e.g., urban terrain). And the potential for

¹ Based on analysis of the AMC AFDD tilt-rotor transport concept.

less-than-perfect information is truly exacerbated when taking into account the full range of cover, concealment, and deception (CCD) tactics and technologies that can be applied by a determined adversary. Thus, information superiority should be exploited when possible, but should not be assumed. A layered, system-of-systems approach toward survivability allows for a much more graceful degradation of effects.

An aggressive preparation of the battlefield phase with JSEAD may be able to neutralize the larger, high-energy emitting SAMs but may have difficulty finding and neutralizing the smaller and highly mobile air defense systems such as the 2S6, especially the MANPADS. While part of the solution might be to fly above the feasible range of these smaller air defense systems (as performed by fixed-wing interdiction missions in OAF in 1999), at some point during the delivery mission, the transport carrying ground forces will have to drop down “on the deck” to complete the delivery. Thus, the smaller and more mobile air defense systems cannot be ignored for the exemplary mission assumed in this analysis.

Against the lower-altitude threats, the use of decoys or unmanned platforms was seen to offer substantial benefit, particularly if they were assumed to resemble the signature of the transport. Even if they cannot be made to match signatures closely, the unmanned platforms can potentially draw fire and improve the survivability odds of the manned transports. In our analysis of a transportation package, the addition of unmanned decoys improved survivability of the transports considerably, especially so with the lower-altitude flight path.²

The addition of weapons such as small HARM-like missiles to enable either a preemptive or reactive and responsive attack of SAM sites further improved the utility of the decoys and enhanced the survivability of the manned transports. By arming the unmanned platforms and giving them the capability to preemptively engage SAM

² For the low-low flight profile, the losses were reduced by as much as 50 percent; for the medium-low flight profile, the losses were reduced by approximately 30 percent.

sites, these platforms become real targets that are more likely to be attacked by the opposing force's systems (i.e., ignoring them may no longer be a wise option).

Lastly, a self-protection system located on transports improved survivability but generally only after other capabilities were added. One of the more decisive methods for defeating an airborne SAM after launch might be to engage it with a form of active protection system (APS), perhaps similar to the one being considered for the FCS ground vehicles. In this case, a small missile with a proximity warhead was postulated.

When this was the only survivability means used, very little improvement in survivability was seen, mostly because of saturation effects.³ However, as part of a system-of-systems in the scenario used for the analysis, this option further improved survivability by as much as 50 percent. By using a layered, system-of-systems approach in the context of the *Kosovo 2015* scenario, survivability for a flexible transport aircraft appears to be a manageable challenge. However, this challenge requires not only a systems integration approach but also a significant investment and maturing of advanced survivability technologies. Developments in unmanned platforms along with corresponding MUM concepts and directed energy systems appear to be important elements that yield a high payoff. There are a number of other areas that can provide improvement to survivability that are not being aggressively pursued.

Broader Observations

Looking beyond a specific scenario or situation, each operational deployment will have a different expected outcome, depending on the mission, threat, and environment. Short-range insertions will be less

³ Simultaneous engagements over a short window of time overwhelm the self-protection system. A similar effect can occur with near-term laser-based systems (ATIRCM/DIRCM) as well.

affected by airspeed considerations. Missions that require only a few aircraft may be more suited to low-altitude operations, much like special operations forces insertions. Missions in low-threat areas that have scattered air defense systems may call for a combination of air and ground movement. Perhaps the potential range in effectiveness argues for preserving as many deployment options as possible in a flexible transport.

Clearly, a robust system-of-systems survivability approach will entail considerable investment to reach fruition. However, many of the components discussed in this research have other applications outside of transport survivability. Some of the technologies, particularly in the areas of individual protection systems, are to some extent being pursued and developed outside the United States.

Perhaps some of the expense (and risk) can be offset by the future needs that may emerge in the commercial aircraft world. That is, in addition to improving the odds of survival of military aircraft, many of these technologies can provide useful crossover to protect commercial aircraft. The adaptation of advanced survivability suites to U.S. commercial aircraft is being evaluated by the U.S. Congress.⁴

Given the ongoing proliferation of air defense systems, the sensible approach for ensuring the survivability of the flexible transport aircraft is to initiate a broad R&D and S&T approach that covers many areas of protection. Ideally, a fully integrated and layered survivability capability might only be used when mission priority dictates a need—as these are sure to be risky missions by today's standards. In many instances, using flexible transports to bring ground forces close to the battle (seam or edge) may be the more practical, logical, and common use of such aircraft. In these cases, the survivability capabilities would still apply but perhaps more as a contin-

⁴ Protecting commercial aircraft against SAM attacks is already being given consideration; costs are estimated to range from \$1 million to \$3 million to integrate an IR countermeasure suite in commercial aircraft. See C. Bolkom and B. Elias, *Homeland Security: Protecting Airliners from Terrorist Missiles*, Report for Congress, Congressional Research Service, February 12, 2003.

gency or a hedge for uncertainty. This uncertainty will certainly increase in importance if a new transport is developed and fielded during a time when the potential adversary can adapt new methods for countering such aircraft and as modern air defense systems and technologies become more sophisticated, continuing to proliferate on tomorrow's battlefield.

The Utility of Operational Maneuver

Although operational maneuver has been the governing factor affecting the weight of the combat vehicles associated with the current and future forces (LAV III and FCS, respectively),¹ its overall importance has seemingly been overlooked in the effort to rebalance the ground combat equation. Even now, the current plan for achieving air-based operational maneuver involves the use of the C-130 fleet of aircraft to deploy future forces. As capable as the C-130 aircraft has proven to be, it has limited operational flexibility, especially in light of what could be available in the future. This inflexibility is especially apparent in countries with less developed infrastructures, which may represent the typical venue for future ground combat as the United States continues its global war on terrorism and responds to emergent small-scale contingencies (SSCs).

The number of airfields capable of serving the C-130 is limited, and these airfields are likely to be distant from potential battle areas

¹ Interestingly enough, operational (not strategic) maneuver provided much of an early rationale for going to lighter-weight vehicles, in particular to satisfy Joint Vision 2010 requirements. See research that was conducted for the Defense Science Board in 1998, J. Matsumura, R. Steeb, E. Isensee, T. Herbert, S. Eisenhard, and J. Gordon, *Joint Operations Superiority in the 21st Century: Analytic Support to the Defense Science Board*, Santa Monica, CA: RAND Corporation, DB-260-A/OSD, 1999.

The Army requirement entailed the use of “non-strategic assets” to operationally deploy the forces; this requirement was essentially interpreted to mean that “the vehicles have to be transportable by the Lockheed Hercules C-130J intratheater airlifter,” which translates to a weight of less than 20 tons.

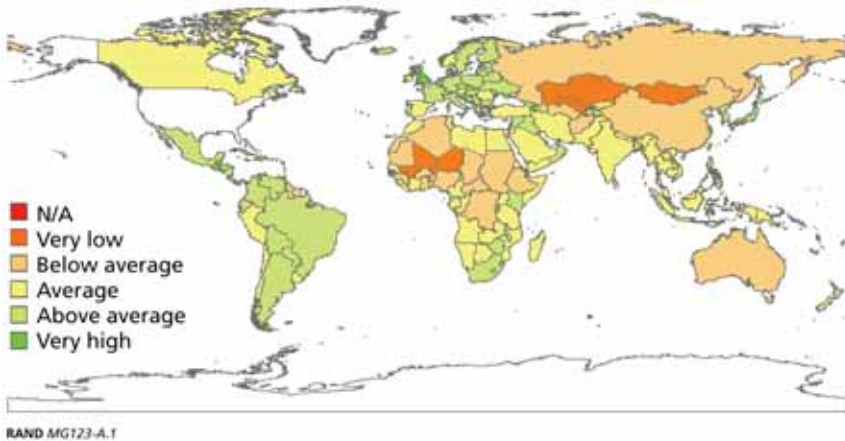
and engagement zones. A quick-look analysis of the world's airfields reveals that the average (unweighted) density of C-130-capable airfields across 173 countries is approximately one airfield for every 10,200 square kilometers.² Taken at statistical face value, this translates to at least 50 kilometers of additional movement (assuming straight-line distance) required to get to a randomly specified location after deployment by a C-130 to the nearest airfield.

In more austere parts of the world, the distance can be significantly longer. As an example, the C-130 airfield density in Sudan is approximately one airfield for every 46,600 square kilometers; in Mongolia it is one airfield per every 55,900 square kilometers, which translates to well over a 100-kilometer road march. Less developed countries or those with a lower population density will likely have less ground infrastructure than found in more developed or populated nations, further increasing the distance and complexity of the required ground movement. See Figure A.1 for how density varies in different parts of the world.

In addition, C-130-capable airfields will be able to handle only a limited number of these aircraft at one time. Specifically, the airfield maximum on ground (MOG) factor will place a limit on how much throughput an airfield will allow. Many airfields capable of handling C-130 aircraft are relatively restrictive and thus could sustain only a few aircraft at a time. As a result, the time to move a battalion consisting of over a few hundred combat vehicles could easily extend to a few days or more, especially when considering that the airfield could also have to accommodate other military functions. The time issue is likely to become a critical factor if large numbers of vehicles need to be moved.

² C-130 airfields are defined as airports with either paved or unpaved runways that are at least 3,000 feet long. Data was taken from the *CIA World Factbook 2000* and *Jane's Land-Based Air Defence Systems 2001–2002*. Also see the website <http://www.fas.org> for information and specifications for various cargo aircraft.

Figure A.1
Comparison of C-130 Airfield “Density” in Different Parts of the World



Another option might be to use larger airfields that are much less MOG-constrained; however, few of these are available. The average density of such airfields across the globe is remarkably lower than C-130-sized airfields. An analysis suggests that of the 136 countries that have C-5-capable airfields, the average density (unweighted) is approximately one airfield for every 176,500 square kilometers.³ This translates to additional movement of over 225 kilometers by ground (again, assuming straight-line distance). Approximately 20 percent of the countries in the world do not have any airfields that can sustain the C-5 class of aircraft.

In sum, it is an unlikely prospect that the C-130 aircraft will allow future combatant commanders to fully capitalize on the inherent air deployability feature of current and future forces.⁴ *Indeed, it might*

³ Here, we assume airfields that are C-5 capable have runways that are paved and at least 10,000 feet long.

⁴ Clearly, there are many additional factors that can also affect the distance and time required to operationally maneuver forces. These include access to airspace and airfields, willingness to operate on surfaces other than recorded airfields, and susceptibility of the airfield to attack, among others.

be quite possible to deploy a brigade into theater in a few days, and then require several more days (over a two-step process) to move the force into positions where it can be effective.

Several other future intratheater aircraft have been explored as possible alternative carriers, including various fixed-wing aircraft alternatives. One of the farthest along programmatically is A400M, being developed by Airbus for several European countries; this aircraft offers considerably larger payload/range capability over a C-130. Also, the notional Advanced Theater Transport (ATT), one concept proposed by the Boeing Phantom Works, improves the payload/range and greatly shortens the takeoff and landing distances relative to that of the C-130.

Both of these aircraft, however, come with limitations similar to those of the C-130 in that they require airfields to operate, which may pose an unnecessary constraint to exercising flexible operational maneuver. Further, looking toward the future, such airfields could represent key vulnerabilities for future forces, as they can become targets of enemy activity.

In response to the limitations of traditional fixed-wing aircraft, a number of novel rotary-wing aircraft have also been proposed as alternative operational assets to the C-130. Two interesting concepts include a large robotic helicopter proposed by Sikorsky called the *Sky-crane* and a notional tilt-rotor concept proposed by Army Materiel Command (AMC), Aeroflightdynamics Directorate (AFDD) Research Laboratory (see Figure A.2 for artist renditions of these rotary-wing concepts).

The basic advantage behind such rotary-wing concepts is that they can deploy the combat vehicles directly into battle positions. With vertical take-off and landing capability, they could perform relatively smooth pick-up, emplacement, and repositioning of the LAV III and FCS vehicles, circumventing the aforementioned MOG problem and potentially eliminating the need for a lengthy ground march to get into position. In addition to faster response time to deploy forces into battle positions, this capability could be used as an

Figure A.2
Images of the Sikorsky “Skycrane” Robotic Carrier and a Notional Tilt-Rotor Concept



RAND MG123-A.3



SOURCE: Images are reproduced here with permission from Sikorsky and Dr. Michael Scully with AMC AFDD.

integral part of combat itself, allowing the exploitation of enemy positions through rapid flanking operations and closing of resupply routes that might not otherwise be possible. This critical attribute of being able to deploy quickly through *vertical envelopment* (in which troops are air-dropped or air-landed at the rear or flanks of a force or other key locations on the battlefield) lies at the heart of U.S. Army Training and Doctrine Command’s (TRADOC’s) air mechanization operational concept.

However, questions have been raised about the cost as well as the survivability of the rotary-wing aircraft needed to support the vertical envelopment concept. An early concept for what was then called the future transport rotorcraft (FTR) was essentially put on hold for just these reasons.⁵

Although affordability and survivability remain key issues to date, new concepts and technologies, along with pruned numbers of

⁵ The initial push for FTR envisioned several hundred transports that would deliver entire brigades *en masse*. With an estimated need on the order of 1,000 and a cost of \$100–\$150 million per aircraft, there was no room in the Army’s budget for such a large undertaking. And, given their estimated size and speed, these aircraft were seen as liabilities that would not be able to survive even in relatively modest air defense environments.

these aircraft and the potential for joint coordination, can make such an important capability available sometime in the future.

Terms of Reference for ASB Study

The following pages reproduce the terms of reference (TOR) for the 2002 Army Science Board Aviation Study.



DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY OF THE ARMY
ACQUISITION LOGISTICS AND TECHNOLOGY
103 ARMY PENTAGON
WASHINGTON DC 2031-0103



05 MAR 2002

REPLY TO
ATTENTION OF

Mr. Michael Bayer
Chair, Army Science Board
2511 Jefferson Davis Highway
Suite 11500
Arlington, Virginia 22202

Dear Mr. Bayer:

I request that the Army Science Board undertake a Study to provide a Science and Technology (S&T) and Research and Development (R&D) roadmap to meet future Army aviation needs. Recently, Army Aviation Science and Technology Strategy shifted its major focus from evolving manned to developing unmanned air vehicles to support the Transformation Path. The study should address the topic in a Joint context, including Defense Advance Research Projects Agency (DARPA) activities, and take into account commercial developments and services.

Background:

As the Army moves to a system of systems approach for the Future Combat Systems and the entire Objective Force, we need to synchronize the roles of manned and unmanned aviation in the Objective Force. Currently, Army modernization is focused on the acquisition and fielding of Comanche and improvements to Apache and selected portions of the Army Aviation fleet. At the same time, the S&T community is investing in new aviation developments/roles for fixed and rotary wing, including unmanned air vehicles of several classes. Army Transformation clearly expands the roles of aviation for Power Projection, Operations, and Sustainment.

Terms of Reference: The Army Science Board should address the following issues and matters in formulating the previously described roadmap:

1. Study manned and unmanned aviation needs, roles, and missions, including the United States Army Training and Doctrine Command (TRADOC) user requirements and the operational and organizational documents, for the Legacy, Interim and Objective Forces, the means to support these, and modernization planning in the Army, Department of Defense (DoD), and commercial sectors.

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- 2 -

2. With respect to Unmanned Air Vehicles (UAV):

a. Study the roles and missions of autonomous and semi autonomous systems, teaming with manned aircraft, and armaments. Consider Combat, Combat Support and Combat Service Support missions.

b. Address survivability, affordability, and sustainment issues from the S&T perspective.

c. Identify major S&T challenges associated with developing, fielding, and sustaining an Army UAV fleet and discuss potential alternatives. Review Army, other service, and DARPA S&T and R&D investments and assess potential benefits, associated risks, and apparent areas of omission.

d. Consider Army policy as transmitted to Congress on the future use of UAVs in the Army's 2001 Report to Congress on tactical unmanned air vehicles (TUAV).

3. Examine required C4ISR architectures to link Apache and Comanche to the Joint Strike Fighter, F-22, legacy aircraft and Air Force, Navy, and Army UAV. Consider the development, fielding, and sustainment of these linkages.

4. Study the Comanche air-to-air mission and propose armament solutions. Consider the feasibility of the common missile as a follow-on to Hellfire.

5. Consider the feasibility of additional of aircrew missions of controlling UAV and the requirement to act as the air battle commander in a net-centric environment.

6. Determine Objective Force cargo airlift requirements and the feasibility of emerging technology to support a follow-on to the CH47 Chinook.

7. Consider innovations supported by industry.

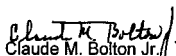
The roadmap should also provide alternatives for fulfilling needs.

Study Sponsorship: The Assistant Secretary of the Army, for Acquisition, Logistics and Technology will be the principal sponsor along with the Deputy Chief of Staff for Operations and Plans, and the Deputy Chief of Staff for Programs.

- 3 -

Schedule: Initiate the study in January 2002, and complete it by June 2002. Perform an interim review in March 2002. Conduct the Study within the provisions of Public Law 92-463 (the Federal Advisory Committee Act) and appropriate DoD and Army regulations. It is not anticipated that the study will need to go into any particular matters within the meaning of Section 202 of Title 18, U.S. Code, nor will it place any member in the position of acting as a procurement official.

Sincerely,

Handwritten signature of Claude M. Bolton Jr. in cursive script.

Claude M. Bolton Jr.
Assistant Secretary of the Army
(Acquisition, Logistics and Technology)

Description of the Modeling Approach for APS/SLID

The modeling of the active protection system (APS) and small low-cost interceptor device (SLID) in RJARS follows the general flight dynamic algorithms used for air-to-air combat. The aircraft is assumed to have a suite of self-defense capabilities. It is equipped with a fire control radar (the data for the APG-70 were used in these cases) and a notional IR missile launch detection system. Also assumed are a number of air-to-air missiles, which were used as surrogates for the SLID. In this analysis, a command-guided (radar) missile was used, with a maximum range assumed to be 5 kilometers.

The operation proceeded in the following manner. If the SAM to be intercepted was radar-guided, the information that a SAM had been launched was collected by the airborne warning receiver, which correlated the signature of the illuminating radar. If the SAM was IR-guided, an IR warning system, which stochastically represented the probability of detection at missile launch (as a function of observation angle) provided the launch information.

Upon detection of the incoming missile, the fire control radar acquires it and tracks the approach. All radar tracking operations are standard, depending on the radar's own characteristics and the radar cross-section of the incoming missile. The geometrical cross-section projected toward the aircraft was used. For most radar-guided missiles, the approach is toward the aircraft with a slight lead angle, so the radar cross-section is near to the nose area of the missile. The radar tracks the missile and, when it is within the operating range of the aircraft, launches the intercept missile.

This missile flies toward the incoming missile, guided by a semi-active radar illuminator and a proportional navigation system. Because of the high relative speeds of the SAM and the intercepting missile, the flight time is typically from 3 to 5 seconds. High-G maneuvering capability is required. The intercepting missile flies to closest approach and then executes an endgame in which the kill probability is a function of the minimum miss distance and the relative orientation of the two vehicles. If the kill is successful, the radar returns to tracking the SAM launcher. If the kill is unsuccessful, another missile can be launched; however, it was determined that due to the short timelines associated with the engagement, a second launch was not likely.

The test runs showed that the miss distance of the intercept missiles at closest approach varied between 5 and 100 feet. Since the kill radius was assumed to be only 15 feet, the most frequent result was a miss. If the intercept was successful, however, there was often enough time (particularly at medium-altitude ingress) for an enemy SAM site to fire another SAM and guide it to target before the aircraft went out of range or out of visibility. The improvement in survivability by the assumed intercept system had limited end effectiveness when used by itself, primarily because of the combined probabilities of successful engagement along with the high number of SAM sites, which can fire multiple missiles if needed. If a larger and more powerful intercept missile were used, it could improve the odds of successful engagement, but it would involve a greater weight penalty on the aircraft.